The Economic Impact of Climate Change and Climatic Variability on Agriculture in Northeast Thailand

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy

by

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Abstract

The main aim of this thesis is to assess the economic impact of climate change and climatic variability on agriculture in Northeast (NE) Thailand. Climate change is a slow and complex phenomenon. Therefore, decision-making in climate change context involves long-time scales and that have led uncertainties associated with many risks.

To assess the impact of climate change in agriculture as well as supporting long-term adaptation planning, long-term climate change scenarios are required. This study achieved this requirement by developing long-term climate change scenarios for NE Thailand under the SRES A2 and B2 climate change scenarios for 2020s, 2050s, and 2080s based upon data from the SEA START RC.

One of the more significant findings to emerge from this study is that the assessment of climate change impacts on NE Thailand agriculture through a careful consideration of spatial issues in the Ricardian framework that this study has undertaken would be useful in providing a more accurate picture of the potential impacts of climate change on farmer income in NE Thailand.

By the end of the 21st century (2080s), NE Thailand farmers of 62 sub-districts in 8 provinces are expected to experience the severe impact of climate change. A full implementation of the key planned adaptation, the IWRM, would therefore be required to alleviate the risk to climate change in NE Thailand agricultural sector.

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Abbreviations

ADB	Asian Development Bank
CBD COP-9	the 9th Conference of the Parties to the Convention of Biological Diversity
CCAM	Conformal Cubic Atmospheric Model
CDM	Clean Development Mechanism
CMIP	Coupled Model Intercomparison Project
DESA	Department of Economic and Social Affairs, United Nations
DNA-CDM	Designated National Authority for Clean Development Mechanism
DOPA	Department of Provincial Administration
DWR	Department of Water Resource
EC	European Commission
ECHAM	European Centre Hamburg Model
EU	European Union
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GHGs	Greenhouse Gases
GMS	Greater Mekong Subregion
GRP	Gross Regional Product

IDW	Inverse Distance Weight
ICT	Information and Communication Technology
ICTP	International Centre for Theoretical Physics
IPCC	Intergovernmental Panel on Climate Change
JGSEE	Joint Graduate School of Energy and Environment
LDD	Land Development Department
MA	Millennium Ecosystem Assessment
MoAC	Ministry of Agriculture and Cooperatives
MoNRE	Ministry of Natural Resources and Environment
NCCC	National Committee on Climate Change
NE	Northeast
NESDB	Office of National Economic and Social Development Board
NSO	National Statistical Office
OAE	Office of Agricultural Economic
ONEP	Office of Natural Resources and Environmental Policy and Planning
PRECIS	Providing REgional Climates for Impacts Studies
R&D	Research and Development
RCPs	Representative Concentration Pathways
REDD	Reducing Emissions from Deforestation and Forest Degradation
RCM	Regional Climate Model

RF	Radiative Forcing
RIF	Regional Investment Framework
SEA START RC	Southeast Asia Regional Centre of the Global Change **S**ys**T**em for **A**nalysis, **R**esearch and **T**raining Network
SRES	IPCC Special Report on Emissions Scenarios
SREX	IPCC Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
TAT	Tourism Authority of Thailand
TEEB	The Economics of Ecosystems and Biodiversity
THB	Thai Baht
TMD	Thai Meteorological Department
TRF	Thailand Research Fund
UK	United Kingdom
UNDP	United Nations Development Programme
UNESCAP	United Nations, Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children's Emergency Fund
USDA	United States Department of Agriculture
VIC	Variable Infiltration Capacity Hydrological Model
WRF	Weather Research and Forecasting
wrt	with reference to

Units

CO_2e	carbon dioxide equivalent
°C	degree Celsius
GtC yr^{-1}	gigatonnes carbon per year
J	joule
km^2	square kilometre
m	metre
mm	millimetre
Mm^3	million cubic metre
ppb	parts per billion
ppm	parts per million
W m^{-2}	watts per square metre

Chapter 1

Introduction

Recent years have seen adaptation to climate change been brought to attention of policy planners in Southeast Asia as it is believed that future climate change would bring immense impact to the region where people are considered highly exposed to climate risk (Chinvanno, 2011). Thus, there is a need for information on the potential impacts of climate change on various climate sensitive sectors such as water resources, agriculture, coastal and marine resources, and forestry (Asian Development Bank-ADB, 2009; Kumar, 2009). Northeast Thailand is one of the country's most vulnerable regions in terms the impact of climate change because of its unique economic characteristics. A large proportion of its labour force is employed in agriculture – 53.4% of the region's total employment (National Statistical Office-NSO, 2010), and more than 3 million people still live below the poverty line with poor access to a healthy and safe environment (The Office of National Economic and Social Development Board-NESDB, 2013a). Given the importance of agriculture in Thailand, the impacts of climate change on agriculture have received considerable attention in Thailand as they could undermine Thailand's ability to ensure food security for the domestic and world population and affect the livelihood of a vast majority of the population (Royal Thai Embassy, Berlin, 2010).

Appropriate policies and measures to address climate change must ensure sustainability and minimize the adverse impacts of climate change in the region.

The major problems for policy-makers in formulating the Northeastern economic and social development strategy stem from natural resource deterioration and poverty in the region.

This chapter includes the introduction, purpose of the study, objectives of the study and need for the study.

1.1 Introduction

The tropics are currently around 15°C warmer than the mid-latitudes and more than 25°C warmer than the high-latitudes; and in the future, it is projected that the oceans and coasts will generally warm by around 3°C, the mid-latitudes by more than 5°C, the poles by around 8°C, and a global average warming of around 4°C (Stern, 2007). There are considerable impacts caused by changes in global average surface temperatures. The risk of heat waves, for example, is expected to increase in frequency. The global average sea-level rise from 1880 to 2009 is about 210 mm (Church and White, 2011) According to Stern (2007), warming will change rainfall patterns and will lead to shifts in large-scale weather regimes. Increases in rainfall at high latitudes are predicted while we can expect a drying of the subtropics, with northern Africa and the Mediterranean experiencing significant reductions in rainfall. However, there is more uncertainty about changes in rainfall in the tropics because of complicated interactions between climate change and natural cycles like El Niño, which dominate climate in the tropics (Collins and the CMIP Modelling Groups, 2005). More research is urgently needed in the tropics because of the potential effect on billions of people (Stern, 2007).

One of the recent climate change assessments for Southeast Asia was "The Economics of Climate Change in Southeast Asia: A Regional Review" by the Asian Development Bank (ADB, 2009). This assessment highlighted that climate change is likely to be one of the most significant development challenges confronting Southeast Asia in the 21st century. Southeast Asia consists of 11 independent countries; Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, and Vietnam. Its population is about 560 million with a growth rate of almost 2% annually, compared with the global average of 1.4% (DESA, 2013). In many of its countries, population and economic activities have a high dependence on natural resources and heavy reliance on agriculture for their livelihood, particularly the poor who live at or below the poverty line ($2 or even $1-a-day). As noted by ADB (2009), climate change is already affecting Southeast Asia, as evidenced by increasing mean temperature, changing precipitation patterns, rising sea level, and increasing frequency and growing intensity of extreme weather events. Further, climate change is exacerbating water shortages in many parts of the region, constraining agriculture production, causing forest fires and degradation, damaging coastal and marine resources, and increasing the risk of outbreaks of infectious diseases (ADB, 2009).

Thailand is an independent country that lies in the heart of Southeast Asia. The local climate is tropical and influenced by monsoons, i.e. southwest monsoon and northeast monsoon. According to Thai Meteorological Department-TMD (2010), the climate of Thailand can be divided into three seasons; rainy or southwest monsoon season (mid-May to mid-October), winter or northeast monsoon season (mid-October to mid-February), and summer or pre-monsoon season (mid-February to mid-May). Consistent with the global trend, temperature in Thailand increased by 0.10-0.18°C per decade over 5 decades of observation (ADB, 2009).

According to the World Bank (2012a), in 2011 Thailand suffered the worst floods in more than half a century. It was caused by excessive and continuous rainfall from successive, powerful monsoons and subsequent, numerous dam breaches. Flash floods were reported in several areas in the north in May, and tropical depression Haima arrived in June followed by Nock-Ten in July, the combination of which resulted to widespread flooding. The southwest monsoon in August-September and the northeast monsoon in October added to the flooding, which was making its way into the central plains, filling many major dams to capacity and causing breaches in 10 major flood control structures. The floods inundated more than six million hectares of land (the World Bank, 2012) including approximately 2.2 million hectares of farmland (Office of Natural Calamity and Agricultural Risk Prevention, 2012). More than 13 million people suffered heavy losses during the flooding and the number of people killed rose to 815 with 3 missing (Emergency Operation Centre for Flood, Storm and Landslide, 2012). The rapid assessment led by the World Bank estimated total damage and losses approximately THB 1.43 trillion (USD 46.5 billion). Rough-rice production from the main crop in Thailand, the world's major exporter, was estimated to decline by at least 6 million tons, nearly 25% fall from last year's main crop of 25 million tons, after the worst floods inundated key growing areas

(Phoonphongphiphat, 2011). Crop losses in Thailand threatened global supplies, drove rice price higher and may push more people deeper into hunger and poverty.

The Northeast is the poorest region of Thailand. In 2011, approximately 3.4 million people (18.1% of the 18.8 million total regional population or about 38.8% of 8.8 million the country's total poor) live below the $2-a-day poverty line (NESDB, 2013a). Agriculture is a major economic sector: in 2011, the sector contributed 21.7% of the gross regional product (GRP) at current market 2011 prices (NESDB, 2013b). In 2009, agriculture accounted for 53.4% of the region's total employment (NSO, 2010). Most of the Northeast's poor live in rural areas and rely on the agriculture sector for their livelihoods. In short, agriculture provides a safety net for the poor. However, consistent with the study of ADB (2009), climate change is already affecting this area with rising temperature, changing rainfall pattern, increasing frequency and intensity of extreme weather events leading to massive flooding and drought causing extensive damage to agricultural products, assets and human life (NESDB, 2008). With limited adaptability, the poor in the Northeast are at risk to the impacts of climate change. If no action is taken, poverty will be extensive.

1.2 Purpose of the study

This research aims to assess the economic impact of climate change and climatic variability on agriculture in Northeast Thailand. In particular, the study will examine the following themes:

- How agriculture in Northeast Thailand has been and will be affected by climate change?

- How could farmers in Northeast Thailand best adapt to variability in climate and what adaptation options or strategies are needed to be incorporated into regional development strategy?

1.3 Objectives of the study

There are 3 objectives of the study.

- to determine how changing climate variables including temperature and precipitation are impacting the farmers' income in the region.

- to identify which sub-regional areas/units (provinces, districts or sub-districts, depending on the availability of the data) of NE Thailand are the most risk to climate change

- to examine and develop adaptation measures and policies climate change for the agriculture sector in NE Thailand.

1.4 Need for the Study

- The findings of this study can provide policy makers with the necessary scientific information for future policy decisions in Northeast Thailand.

- The outcome of this study will be applied for assessing the economic impact of climate change and climatic variability on agriculture of other regions in Thailand.

- This work will support 20 Provincial Administrations in Northeast Thailand to incorporate adaptation and mitigation into their provincial development planning processes. These organisations are responsible for implementation and evaluation of the Regional Development Strategy.

- In addition, this project may raise awareness among stakeholders (for example, government, civil society, academia, media, non-government organizations, and private sector) on the urgency of climate change challenges and their potential socio-economic impacts on Northeast Thailand.

Chapter 2

Review of the Literature

The Economic Impact of Climate Change on Agriculture

2.1 Introduction

Agriculture is highly dependent on weather or climate and as such the sector has a very strong relation with climate change (Wreford et al., 2010, Anwar et at., 2012, Maharjan and Joshi, 2013). It is also a significant source of anthropogenic emissions of greenhouse gases (Smith et al., 2007) and it, at the same time, has enormous mitigation potential for reduction of greenhouse gases (Wreford et al., 2010, Maharjan and Joshi, 2013). The impact on agriculture is seen as potentially the most serious impact of climate change in terms of numbers of people affected and the severity of impacts on those least able to cope (Wreford et al., 2010). Therefore, it is crucial for researchers, policymakers and stakeholders understand key information on climate change and its relation to agriculture – and to take action.

This chapter firstly describes current knowledge on climate change and related issues, such as observed changes of the atmosphere and ocean warming, the mass loss of the cryosphere, sea-level rise and the latest concentrations of greenhouse gases, as well as drivers of climate change and greenhouse effect. Secondly, it examines knowledge on economic impact of climate change. This section focuses on the most influential study conducted by Sir Nicholas Stern, "The Economics of Climate Change: The Stern Review", including climate change impacts, costs of climate change, a range of options for cutting emissions, international responses to climate change and key elements of future international frameworks. Further, the studies of the Value of the World's Ecosystem Services and Natural Capital, and the Economics of Ecosystem Services and Biodiversity (e.g. TEEB) are reviewed to highlight the relative importance of ecosystem services and the potential impact on human welfare. Finally, the chapter reviews the linkage between climate change and agriculture. Climate change impacts on agriculture, site and context specification of agriculture, agriculture contributions to greenhouse gases, and the potential options for mitigation and adaptation in agriculture are examined.

2.2 Climate Change

The climate system is a complex and interactive system (IPCC, 2007a). It consists of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. Climate is characterised by the atmospheric component of the climate system. Climate is often defined as 'average weather', usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the accepted period for defining climate is 30 years). Factors determining the Earth's climate include the influence of its own internal dynamics as well as changes in external factors that affect climate (called 'forcings'). External forcings include natural phenomena such as modulations of the solar cycles, volcanic eruptions, as well as human-caused changes in atmospheric composition (IPCC, 2014).

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (UNFCCC, undated). Additionally, the Intergovernmental Panel on Climate Change (IPCC) defines climate change as “a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer” (IPCC, 2014). Thus, there is a difference between the UNFCCC’s and the IPCC’s definitions. The UNFCCC considers only to the human activities that alter the composition of the global atmosphere, while the IPCC also focuses on a natural variability itself. The definition given by IPCC is accepted as the broader definition of climate change (Maharjan and Joshi, 2013).

Global-scale observations of the climate system from the instrumental era began in the mid-19th century for temperature and other variables (IPCC, 2013). Palaeoclimate reconstructions extend some records back hundreds to millions of years, providing a comprehensive view of the variability and long-term changes of the climate system. According to IPCC (2013), many observations since 1950s unequivocally indicate that the atmosphere and ocean have warmed, the amount of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

2.2.1 Atmosphere

More complete observations allow greater confidence in estimates of tropospheric temperature changes (IPCC, 2013) and IPCC (2013) points out that globally the troposphere has warmed since the mid-20th century. For the Earth's surface warming, averaged combined land and ocean surface temperature over the period 1880-2012 data show an increasing trend with a warming of 0.85 [0.65 to 1.06] °C. Each of the last three decades has been successively warmer than any preceding decade since 1850 (Figure 1.1(a)). Figure 1.1(b) shows a map of the observed surface temperature change from 1901 to 2012 derived from regional temperature trends determined by linear regression. Almost the entire globe has experienced surface warming (IPCC, 2013).

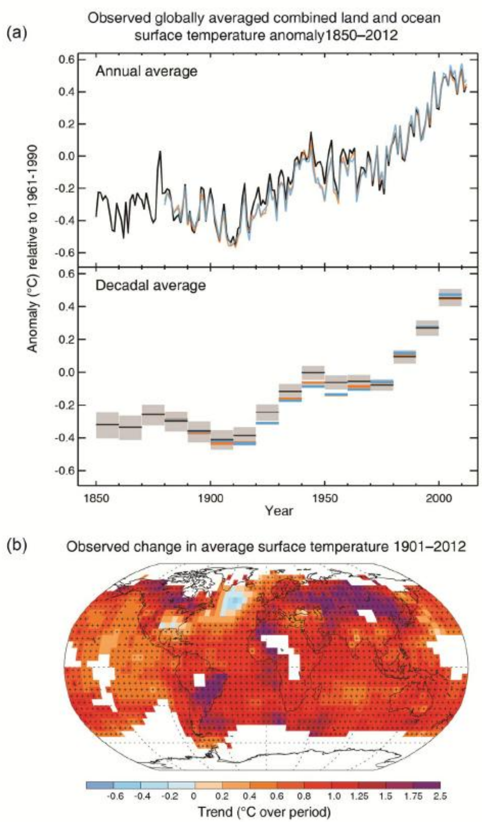


Figure 1.1 Observed change in global temperature (IPCC, 2013)

Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterwards (IPCC, 2013). The intensity or frequency of heavy precipitation events has likely increased in North America and Europe since about 1950, while confidence in changes in heavy precipitation events in other continents is at most medium (IPCC, 2013).

2.2.2 Greenhouse Gases

The atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have all increased to levels unprecedented in at least the last 800,000 years (IPCC, 2013). There is increasing evidence that these changes are have been precipitated by human activity. In 2011 the concentrations of these greenhouse gases were 391 ppm, 1803 ppb, 324 ppb and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively (IPCC, 2013). As noted by IPCC (2013), annual CO_2 emissions from fossil fuel combustion and cement production were 8.3 [7.6 to 9.0] GtC yr^{-1} and from anthropogenic land use change were 0.9 [0.1 to 1.7] GtC yr^{-1} averaged over 2002-2011. In 2011, fossil fuel CO_2 emissions were 9.5 [8.7 to 10.3] GtC yr^{-1}, 54% above the 1990 level. From 1750 to 2011, CO_2 emission from fossil fuel combustion and cement production have released 365 [335 to 395] GtC to the atmosphere, while deforestation and other land use change are estimated to have released 180 [100 to 260] GtC. Totally, cumulative anthropogenic emissions has been up to 545 [460 to 630] GtC; of these emission, 240 [230 to 250] GtC have accumulated in the atmosphere, 155 [125 to 185] GtC have been taken up by the ocean and 150 [60 to 240] GtC have accumulated in natural terrestrial ecosystems (IPCC, 2013).

2.2.3 Ocean

The IPCC (2013) highlights that on a global scale over from 1971 to 2010, the ocean warming is largest near the surface and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade. More than 60% of the net energy increase in the climate system is stored in the upper ocean (0-700 m) and about 30% below 700 m. It is likely that upper ocean heat content has increased by 17 [15 to 19] x 10^{22} J during 40-year period from 1971 to 2010 (IPCC, 2013). It is at the medium confidence that evaporation and precipitation over the oceans have changed due to the changes in regional trends in ocean salinity. It is very likely that regions of high salinity where evaporation dominates have become more saline, while regions of low salinity where precipitation dominates have become fresher since the 1950s (IPCC, 2013).

2.2.4 Cryosphere

Over the last two decades, there is high confidence that the Greenland and Antarctic ice sheets have been losing mass, glaciers around the world have continued to shrink, and Arctic sea ice and Northern Hemisphere spring snow cover have decreased in extent (IPCC, 2013). The average rate of ice loss from glaciers worldwide, excluding glaciers on the periphery of the ice sheets, was very likely 226 [91 to 361] Gt yr^{-1} over the period 1971-2009, and very likely 275 [140 to 410] Gt yr^{-1} over the period 1993-2009. The Greenland ice sheet has very likely substantially lost mass from 34 [-6 to 74] Gt yr^{-1} over the period 1992-2001 to 215 [157 to 274] Gt yr^{-1} over the period 2002-2011 while the Antractic ice sheet has likely lost mass from 30 [-37 to 97] Gt yr^{-1} over the period 1992-2001 to 147 [72 to 221] Gt yr^{-1} over the period 2002-2011 (IPCC, 2013).

2.2.5 Sea Level

It is high confidence that the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia and likely has continued to increase since the early 20^{th} century (IPCC, 2013). Globally averaged rate of sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} during 1901 to 2010, 2.0 [1.7 to 2.3] mm yr^{-1} during 1971 to 2010 and 3.2 [2.8 to 3.6] mm yr^{-1} during 1993 to 2010 (IPCC, 2013). Over the period 1993-2010, global mean sea level rise, with high confidence, is consistent with glacier mass loss and ocean thermal expansion from warming. During the last interglacial period (129,000 to 116,000 years ago), the Greenland ice sheet very likely contributed between 1.4 and 4.3 m to higher global mean sea level with an additional contribution from the Antarctic ice sheet which occurred in the context of different orbital forcing and with at least 2°C warmer than present in high-latitude surface temperature averaged over several thousand years, (IPCC, 2013).

2.3 Drivers of Climate Change

Natural and anthropogenic substances and processes that alter the Earth's climate system are drivers of climate change (IPCC, 2013). Radiative forcing

(RF) is a measure of how the energy balance of the Earth-atmosphere system is influenced when drivers of climate change are altered (IPCC, 2007a). As noted by IPCC (2013), the RF quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750, unless otherwise indicated. RF is usually quantified as the 'rate of energy change per unit area of the globe as measured at the top of the atmosphere', and is expressed in units of 'Watts per square metre.' When RF from a factor or group of factors is evaluated as positive, the energy of the Earth-atmosphere system will ultimately increase, leading to a warming of the system. In contrast, for a negative RF, the energy will ultimately decrease, leading to a cooling of the system. The radiative balance controls the Earth's surface temperature.

Solar radiation supplies energy for the climate system. Most aerosols, for example, reflect solar radiation back to space resulting in cooling of the Earth's climate system (negative RF forcing) while black carbon absorbs solar radiation leading to the warmer climate (positive RF forcing). The estimation of RF is based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models representing observed processes (IPCC, 2013). Total RF is positive and has led an uptake of energy by the climate system; the increase in the atmosphere concentration of CO_2 since 1750 is the largest contribution to total RF (IPCC, 2013).

Figure 1.2 presents RF by emissions and drivers. The total anthropogenic RF for 2011 relative to 1750 is 2.29 [1.13 to 3.33] W m^{-2} (IPCC, 2013). It has grown drastically since 1970 than during prior decades. In 2011, the total anthropogenic RF was 43% higher than that reported in the IPCC Fourth Assessment Report (2007) for the year 2005. IPCC (2013) explains that it is due to a combination of continued increases in most greenhouse gas concentrations and improved estimations of RF by aerosols indicating a weaker net cooling effect (negative RF).

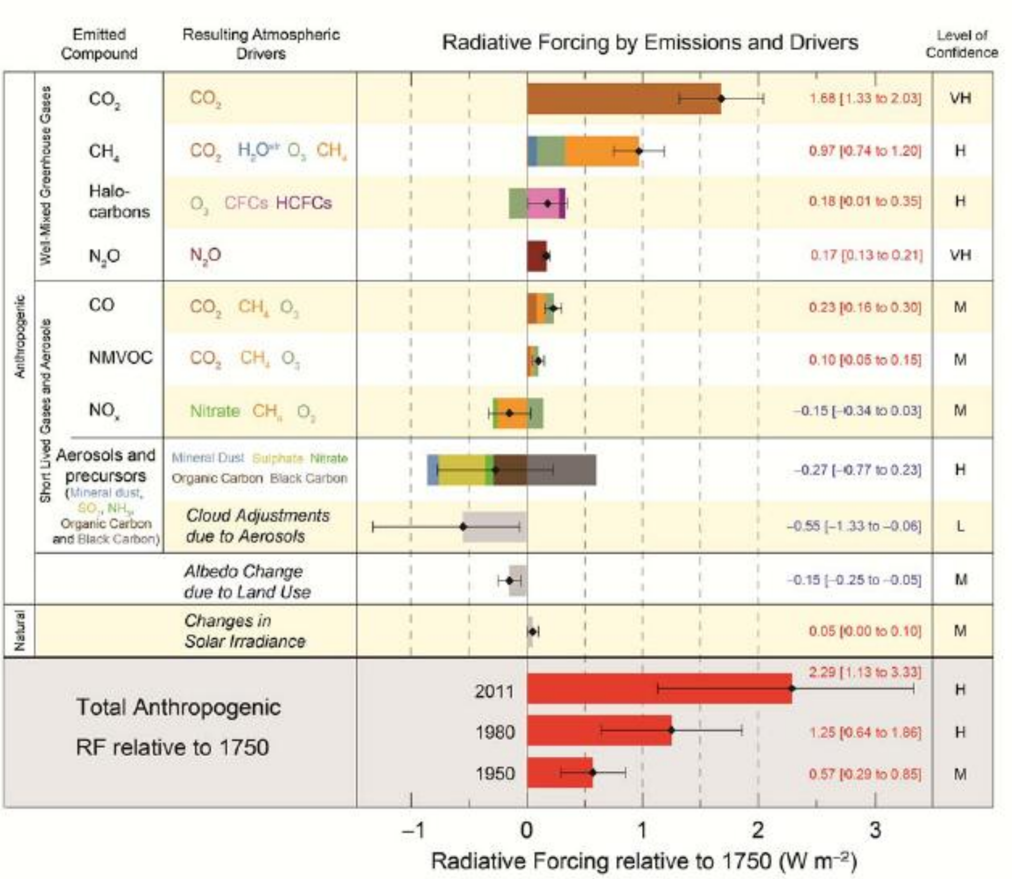


Figure 1.2 Relative Forcing by Emissions and Drivers (IPCC, 2013)

As summarized by IPCC (2013), emissions of well-mixed greenhouse gases (CO_2, CH_4, N_2O, and Halocarbons) have caused a net positive RF of 3.00 [2.22 to 3.78] W m^{-2}. Emission of CO_2 alone have cause an RF of 1.68 [1.33 to 2.03] W m^{-2}, while emissions of CH_4 have caused an RF of 0.97 [0.74 to 1.20] W m^{-2}.

Emissions of stratospheric ozone-depleting halocarbons have caused a net positive RF of 0.18 [0.01 to 0.35] W m^{-2}. The positive RF from all halocarbons, with a reduced RF from CFCs but increases from many of their substitutes, has outweighed the negative RF from the ozone depletion (IPCC, 2013). Emissions of short-lived gases also contribute to the total anthropogenic RF. Emissions of carbon monoxide are virtually certain to have induced a positive RF, while emissions of nitrogen oxides (NO_x) are likely to have induced a net negative RF (IPCC, 2013).

It is with medium confidence that the RF of the total aerosols effect in the atmosphere is -0.9 [-1.9 to -0.1] W m^{-2} (IPCC, 2013). The most massive change in aerosol-induced reflectivity happens when major volcanic eruptions eject material very high into the atmosphere. Rain normally releases aerosols out of the atmosphere in a week or two. However, material from a violent volcanic eruption is sometimes projected far above the highest cloud. These aerosols typically influence the climate for about a year or two before falling into the troposphere and being carried to the surface by precipitation. Major volcanic eruptions can thus cause a drop in mean global surface temperature of about half a degree Celsius that can last for months or even years. Some man-made aerosols also significantly reflect sunlight. Several small eruptions have caused a RF of -0.11 [-0.15 to -0.08] W m^{-2} for the years 2008-2011, which is approximately twice as strong as during the years 1999–2002 (IPCC, 2013).

IPCC (2013) assesses that the total natural RF from solar irradiance changes and stratospheric volcanic aerosols made only a small contribution to the net RF throughout the last century, except for brief periods after large volcanic eruptions. The RF due to changes in solar irradiance is estimated as 0.05 [0.00 to 0.10] W m^{-2}. Satellite observations of total solar irradiance changes from 1978 to 2011 indicate that the last solar minimum was lower than the previous two. It results in a RF of -0.04 [-0.08 to 0.00] W m^{-2} between the most recent minimum in 2008 and the 1986 minimum (IPCC, 2013).

2.4 Greenhouse Effect

The idea of greenhouse effect emerged from the evidence that although the sun's light and heat easily pass through glass and other transparent materials, heat from other non-transparent sources does not (Maharjan and Joshi, 2013). Greenhouse gases act as a partial blanket for the longwave radiation coming from the surface. They keep the Earth's surface warm. This blanketing is known as the natural greenhouse effect. The most important greenhouse gases are water vapour and carbon dioxide. Nitrogen and oxygen have no such effect. Clouds do exert a blanketing effect similar to that of the greenhouse gases but this effect is offset by their reflectivity. Clouds, on the other hand, tend to have a cooling effect on climate. Humankind has dramatically intensified the blanketing effect through the release of greenhouse gases especially carbon dioxide.

Anthropogenic influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (IPCC, 2013). The increasing human-induced greenhouse gas concentrations and other anthropogenic forcings together have been the dominant cause of the observed increase in global average surface temperature since the mid-20th century.

2.4.1 Atmosphere and Ocean temperatures

As assessed by IPCC (2013), it is likely that greenhouse gases contributed a global mean surface in the range of 0.5°C to 1.3°C over the period 1951-2010. Including the contributions from other anthropogenic forcings and the cooling effect of aerosols, greenhouse gases contributed likely to be in the range of -0.6°C to 0.1°C. The natural forcings contributed likely to be in the range of -0.1°C to 0.1°C while internal variability contributed likely to be in the same range of -0.1°C to 0.1°C. Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period (IPCC, 2013). In addition, there is evidence for anthropogenic forcings in substantial contribution to increases in global upper ocean heat content (0-700 m) observed from 1960 to 1980 and influence in some individual ocean basins (IPCC, 2013).

Based on direct satellite measurements of total solar irradiance, there is high confidence that the increase in global mean surface temperature over the period 1986 to 2008 have not been contributed from changes in total solar irradiance (IPCC, 2013). The 11-year cycle of solar variability, however, influences decadal climate fluctuations in some regions with medium confidence (IPCC, 2013). No robust association between changes in cosmic rays and cloudiness has been identified (IPCC, 2013).

2.4.2 Changes in Global Water Cycle

It is likely that anthropogenic influences have affected the global water cycle since 1960. It is medium confidence that anthropogenic influences have made a significant contribution to observed increases in atmospheric moisture content in the atmosphere. Besides, with medium confidence, these forcings have contributed to global-scale changes in precipitation patterns over land and to intensification of heavy precipitation over land. It is very likely that human influences contributed to changes in surface and sub surface ocean salinity (IPCC, 2013).

2.4.3 Ice Sheet Mass Loss

Anthropogenic influences have very likely contributed to Arctic sea ice loss since 1979, likely to the retreat of glaciers since the 1960s, and likely to the increased surface mass loss of the Greenland ice sheet since 1993 (IPCC, 2013). Due to a low level of scientific understanding, there is low confidence in small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and low confidence in estimates of internal variability in that region. Additionally, there is low confidence in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades (IPCC, 2013).

2.4.4 Global Mean Sea Level Rise

It is very likely that anthropogenic influences have substantial affected to the global mean sea level rise since the 1970s. This is based on the high confidence in an anthropogenic influence that is the two largest contributions to sea level rise are thermal expansion and glacier mass loss (IPCC, 2013).

2.4.5 Climate Extremes

Since the IPCC Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), there has been further strengthening of the evidence for human influence on temperature extremes (IPCC, 2013). It is very likely that observed global scale changes in the frequency and intensity of daily temperature extremes from 1951 to 2010 were caused by human influence, and it is likely that there has been more than doubled the probability of occurrence of heat waves in some locations were contributed from human influences (IPCC, 2013).

2.5 Economic Impact of Climate Change

Recent years have seen an increase in the number of studies aiming to quantify the economic impacts of climate change and among the most influential is The Economics of Climate Change: The Stern Review (ADB, 2009). The Stern Review is the comprehensive analysis of the economic aspects of climate change conducted by Sir Nicholas Stern, Head of the Government Economic Service and a former Chief Economist of the World Bank for the UK Prime Minister and Chancellor (Stern, 2007). It has taken a broad view of the economics required to understand the challenges of climate change.

2.5.1 Climate Change Impacts

According to Stern (2007), the scientific evidence that climate change presents very serious global risks and demands an urgent global response is now compelling. With substantial increases of greenhouse gases concentrations in the atmosphere since the Industrial Revolution and because of the inertia in the climate system, the average global surface temperature increases by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades. If concentrations of greenhouse gases in the atmosphere reach a doubling level, it is likely to commit the Earth to rise of between 2-5°C in global mean temperatures (Stern, 2007). The Review asserts that there would be more than a 50% chance that the temperature rise would exceed 5°C in the longer term and this rise would be equivalent to the change in average temperatures from the last ice age to today. Stern (2007) notes that such a drastic change in the physical world would undoubtedly lead to changes in human geography – where people live and how they live their lives (Stern, 2007).

2.5.2 Costs of Climate Change

Stern (2007) asserts that all countries will be affected. Furthermore, Stern (2007) states that despite contributing the least to the causes of climate change, the poorest countries and populations will suffer earliest and most. The costs of extreme weather, including floods, droughts and storms, are already rising, including for rich countries. There are complex challenges in reducing green house gases emissions; however, the benefit of strong and early action on climate change is large (Stern, 2007). Using the results from formal economic models, the Review estimates that if no action is taken, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If the wider range of risks and impacts is taken into account, the estimate of damage could rise to 20% of GDP or more.

The Review suggests that the risks of the worst impacts of climate change can be significantly reduced if greenhouse gas concentrations in the atmosphere can be stabilise between 450 and 550 ppm CO_2e. In order to stabilise greenhouse gas levels in this range, it would require emissions to be at least 25% below current level by 2050, and perhaps much more. Ultimately, stabilisation – at whatever level – requires that annual emissions be brought down to more than 80% below current levels (Stern, 2007). This is a substantial challenge; however, sustained long-term action can accomplish it at costs that are low in comparison to the risks of inaction. According to Stern (2007), the annual costs of achieving stabilisation between 500 and 550 ppm CO_2e are around 1% of global GDP, if we start to take strong action now.

It has been noted that the direct and indirect cost of climate change could be even lower than that if there are major gains in efficiency, or if the strong co-benefits, for example from reduced air pollution, are measured (Stern, 2007). On the contrary, cost will be higher if innovation in low-carbon technologies is slower than expected, or if policymakers fail to make the most of economic incentives to reduce emissions whenever, whatever and however it is cheapest to do so. It would already be very difficult and costly to aim to stabilise at 450 ppm

CO_2e, if we delay, the opportunity to stabilise at 500-550 ppm CO_2e may slip away (Stern, 2007).

2.5.3 A Range of Options Exists to Cut Emissions

According to Stern (2007), emissions can be cut through increased energy efficiency, changes in demand, and through adoption of clean power, heat and transport technologies. The Review estimates that at least 60% decarbonise would be needed from power sector around the world in order to stabilise atmospheric concentrations at or below 550 ppm CO_2e, and deep emissions cuts will also be required in the transport sector by 2050. The Review and research within the energy arena highlights fossil fuels and coal will continue to be significant in the energy supply around the world despite with very strong expansion of the use of renewable energy and other low-carbon energy sources. Therefore, extensive carbon capture and storage will be essential to allow the continued use of fossil fuels without damage to the atmosphere and economic growth. Additionally, cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes, are also necessary (Stern, 2007).

Stern (2007) asserts that with strong, deliberate policy instruments, it is possible to stabilise emissions in the require range in both developed and developing economies with continuing growth. According to the report, climate change is the worst market failure the world has ever seen, and it further interacts negatively with other market imperfections. Three elements of policy are required for an effective global response including;

- the pricing of carbon,
- low-carbon technologies and
- energy efficiency.

First, the pricing of carbon can be implemented through tax, trading or regulation. Second, it is necessary to support innovation and the deployment of low-carbon technologies. And the third is action to remove barriers to energy efficiency, and to inform, educate and persuade individuals about what they can do to response to climate change (Stern, 2007).

2.5.4 International Response to Climate Change

Because climate change is a global problem, the response to it must be international (Stern, 2007). A response must be based on a shared vision of long-term goals and agreement on frameworks that will accelerate action over the next decade. Whilst, also building on mutually reinforcing approaches at national, regional and international level. Stern (2007) suggests that action on climate change is required across all countries, and it need not cap the aspirations for growth of rich or poor countries. Despite rich countries take on responsibility for absolute reductions in emissions of 60-80% by 2050, the developing world must take significant action too. However, the report stipulates that developing countries should not be required to bear the full cost of this action alone, and they will not have to (Stern, 2007).

Carbon markets in rich countries are already emerging to deliver flows of finance to support low-carbon development, including the Clean Development Mechanism. A transformation of these flows is now required to support action on the scale required (Stern, 2007). As noted by Stern (2007), climate change action also poses significant business opportunities. New markets, for instance, are created in low-carbon energy technologies and other low carbon goods and services. These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly.

With regard to the debate centring on climate change versus economic growth, Stern (2007) argues that the world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and in the structure of economies have created opportunities to decouple growth from greenhouse gas emissions. In fact, ignoring climate change will eventually damage the world economy. Tackling climate change is the pro-growth strategy for the longer term development, and it can be done in a beneficial way for growth of rich or poor countries (Stern, 2007).

Many countries and regions are taking action already: the EU, California and China are among those with the most ambitious policies that will reduce greenhouse gas emissions (Stern, 2007). The UN Framework Convention on Climate Change and the Kyoto Protocol provide a basis for international co-operation, along with a range of partnerships and other approaches. However, more ambitious action is now required around the world. Countries facing diverse circumstances need to use different approaches to make their contribution to tackling climate change. However, action by individual countries is not enough. Each country, however large, is part of the problem. Thus, it is essential to create a shared international vision of long-term goals, and to build the international frameworks that will help each country to play its part in meeting these common goals.

2.5.5 Key elements of Future International Frameworks

Emissions trading, technology cooperation, action to reduce deforestation and adaptation to climate change are key elements of future international frameworks (Stern, 2007). First, the expansion of a global emissions trading scheme is required. Global emission's trading has the potential way to promote cost-effective reductions in emission and to boost action in developing countries. Besides, strong target in rich countries could stimulate flows equivalent to tens of billions of dollars each year to support the transition to low-carbon development paths (Stern, 2007).

Second, informal technology cooperation as well as formal agreements can raise the effectiveness of investments in innovation around the world. Globally, support for energy R&D should at least doubled, and support for the development of new low-carbon technologies should increase up to five-fold. International standard of commodities is a powerful way for energy efficiency (Stern, 2007).

Third, the loss of natural forests around the world is one of the major contributors to global emissions each year, indeed, more than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions (Stern, 2007).

Finally, the poorest countries are most vulnerable to climate change; therefore, it is essential that climate change be fully integrated into development policy. Additionally, rich countries should honestly encourage the developing world through overseas development assistance. International funding should also support improved regional information on climate change impacts, and research into new crop varieties that will be more resilient to drought or flood (Stern, 2007).

2.6 The Economics of Ecosystems and Biodiversity

2.6.1 The Value of the World's Ecosystem Services and Natural Capital

The services of ecological systems and the natural capital stocks contribute to human welfare both directly and indirectly. These services are critical to functioning of the Earth's life support system, and therefore account for part of the total economic value of the planet. Ecosystem services, however, are not fully captured in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital. They are typically neglected in policy decision, which may ultimately compromise the sustainability of humans in the biosphere (Costanza et al., 1997).

There have been many studies in the past few decades aimed at estimating the value of a wide variety of ecosystem services. The attempt to estimate the total economic value of ecosystem services is limited by huge uncertainties about a realistic representation of ecosystem dynamics and interdependence. Therefore, we may never have a very precise estimate of the value of ecosystem services. As natural capital and ecosystem services become more stressed and scarce in the future, an estimate of value of ecosystem services, even the crude initial estimate, is a useful starting point to highlight the relative importance of ecosystem services and the potential impact on our welfare of continuing to squander them.

The study of 'The Value of the World's Ecosystem Services and Natural Capital' constructed by Costanza et al. in 1997, estimated for the first time (TEEB, 2010), presented a minimum incremental or marginal value of 17 ecosystem services for 16 biomes. For the entire biosphere, the value was estimated to be in the range of \$16-54 trillion (10^{12}) annually, with an average of \$33 trillion per year. About 63% of the estimate value was contributed by marine systems (\$20.9 trillion per year). Most of this came from coastal systems (\$10.6 trillion per year). About 38% of the estimated value came from terrestrial systems, mainly from forests (\$4.7 trillion per year) and wetlands (\$4.9 trillion per year). The real value is almost certainly much larger (Costanza et al., 1997).

2.6.2 The Economics of Ecosystem Services and Biodiversity (TEEB)

The recent and influential work of 'The Economics of Ecosystem Services and Biodiversity' (TEEB), was initiated by the European Commission (EC) and Germany in 2007 (TEEB, 2010). It was earlier proposed, at the meeting of the G8+5 Environment Ministers in Potsdam, Germany in March 2007, that a global study on 'the economic significance of the global loss of biological should be undertaken. The proposal was subsequently endorsed by the G8+5 leaders at the Heiligendamm Summit in June 2007 and later an interim report of the study (TEEB, 2008) was presented at the 9th Conference of the Parties to the Convention of Biological Diversity (CBD COP-9) in Bonn, Germany in May 2008. The interim findings were successful in providing evidence that significant global and local economic costs and human welfare impacts are attributable to the ongoing losses of biodiversity and degradation of ecosystems (TEEB, 2010).

At the CBD COP-9, however, delegates stressed the need for a more elaborate valuation framework and methodologies adopted in the TEEB's Phase I and a further focus on engaging end-users, i.e. policy makers, business executives, consumers and local communities. Therefore, in TEEB's Phase II the scientific basis of the economics of ecosystems and biodiversity has been addressed and specific audiences, including policy makers, administrators, business or consumers have been acknowledged (TEEB, 2010).

2.6.3 Defining Ecosystem, Biodiversity and Ecosystem Services

According to TEEB (2010), nowadays there is an increasing level of awareness of the importance of ecosystems and biodiversity to human welfare but large scale loss of biodiversity and degradation of ecosystems still continues. Understanding of the economic value of the ecosystem is essential as a tool that may contribute in the long run to internalise and promote a respect for nature into social life. To analyse the 'Economics of Ecosystems and Biodiversity' a practical and consistent definition and typology of ecosystems (and biodiversity) is necessary.

The definitions used in the TEEB assessment are largely consistent with the definitions of the United Nations' 1922 Convention on Biological Diversity. An *ecosystem* is the complex of living organisms and the abiotic environment with which they interact at a specified location. *Biodiversity* is the sum total of organisms including their genetic diversity and the way in which they fit together into communities and ecosystems (TEEB, 2010). TEEB proposed a typology of 12 main biomes including;

- Marine/open ocean
- Coastal systems
- Wetlands
- Lakes and rivers
- Forests
- Woodland and shrubland
- Grass and rangeland
- Desert
- Tundra
- Ice/rock/polar
- Cultivated areas and
- Urban areas.

In addition, TEEB stated *ecosystem services* as 'the direct and indirect contributions of ecosystems to human well-being and can benefit people in multiple and indirect ways (TEEB, 2010). TEEB proposes a typology of 22 ecosystem services, mainly following the MA classification, split into four main categories: provisioning, regulating, habitat, and cultural and amenity services (see Table 2.1).

Table 2.1 Typology of ecosystem services in TEEB

Main service types	
PROVISIONING SERVICES	
1	Food (e.g. fish, game, fruit)
2	Water (e.g. for drinking, irrigation, cooling)
3	Raw materials (e.g. fibre, timber, fuelwood, fodder, fertilizer)
4	Genetic resources (e.g. for crop-improvement and medicinal purposes)
5	Medicinal resources (e.g. biochemical products, models and test-organisms)
6	Ornamental resources (e.g. artisan work, decorative plants, pet animals, fashion)
REGULATING SERVICES	
7	Air quality regulation (e.g. capturing (fine) dust, chemicals, etc.)
8	Climate regulation (incl. C-sequestration, influence of vegetation on rainfall, etc.)
9	Moderation of extreme events (e.g. storm protection and flood prevention)
10	Regulation of water flows (e.g. natural drainage, irrigation and drought prevention)
11	Waste treatment (especially water purification)
12	Erosion prevention
13	Maintenance of soil fertility (incl. soil formation) and nutrient cycling
14	Pollination
15	Biological control (e.g. seed dispersal, pest and disease control)
HABITAT SERVICES	
16	Maintenance of life cycles of migratory species (incl. nursery service)
17	Maintenance of genetic diversity (especially through gene pool protection)
CULTURAL and AMENITY SERVICES	
18	Aesthetic information
19	Opportunities for recreation and tourism
20	Inspiration for culture, art and design
21	Spiritual experience
22	Information for cognitive development

Source: TEEB (2010)

2.6.4 TEEB-conceptual framework

(1) Ecosystem structure, processes and functions

Figure 1.3 shows the TEEB framework which starts with the upper left-hand box which distinguishes ecosystem structure, processes and functions. *Ecosystem functions* are subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services (TEEB, 2010). These interactions may be physical (e.g. infiltration of water, sediment movement), chemical (e.g. reduction, oxidation) or biological (e.g. photosynthesis and denitrification), whereby 'biodiversity' is more or less involved in all of them.

(2) Typology of ecosystem services

As noted above, there are four main groups of ecosystem services including provisioning, regulating, habitat, and cultural and amenity services. Before economic valuation can be applied, the performance or availability of ecosystem services has to be measured in biophysical terms, either using some direct measures of services or using of proxies depending on the state of ecological knowledge and the data availability. Actual measurements of ecosystem services should be divided into;

(i) the capacity of an ecosystem to provide a service (e.g. how much fish can the lake provide on a sustainable basis) and

(ii) the actual use of that service (e.g. fish harvesting for food or for use in industrial processing).

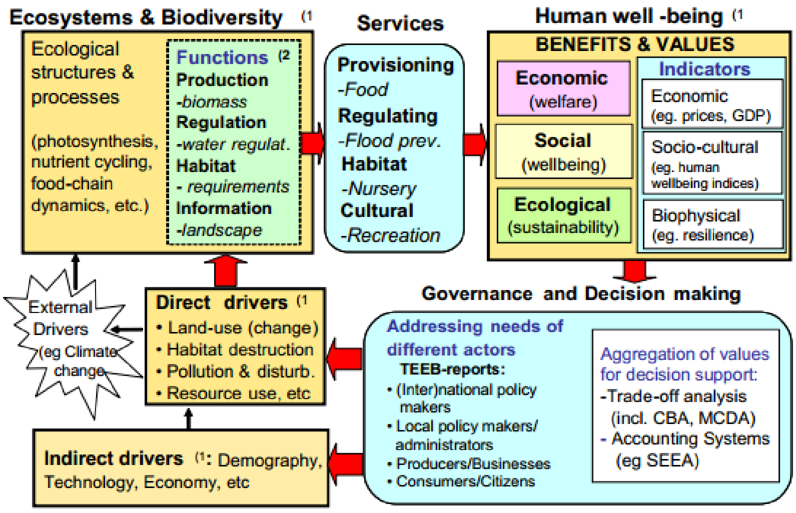


Figure 1.3 TEEB Conceptual framework for linking ecosystems

and human well-being (TEEB, 2010)

Notes: 1) the four bold-lined boxes coincide with the overall MA-Framework.

2) subset of ecosystem processes & components that is directly involved in providing the service.

Measurement of the importance (value) of that fish in terms of nutrient value, a source of income and/or way of life is then part of the 'human value domain' (TEEB, 2010).

To apply valuation, it is necessary to distinguish between potential and actual use of service with direct use value (notably provisioning and some cultural services), and services that have indirect use (notably regulating, habitat and some services). Most ecosystems provide a bundle of services; in that the use of one service generally affects the availability of other services. Therefore, (economic) valuation should take due account of not only (marginal) values from the flows of individual services but also the “stock value” (i.e. the entire ecosystem) providing the total bundle of services. When applying economic valuation, it is required the actual management regime of the ecosystem which will influence the expected value of future flows of services in different ways depending on whether it leads to sustainable or unsustainable uses (Mäler et al., 2008).

(3) Human well-being

The upper right-hand box in figure 3 relates human well-being. The TEEB framework makes a distinction between three main types of benefits and values including ecological, socio-cultural and economic benefits and values. Ecological importance (value) of ecosystems has been articulated in reference to the casual relationships between parts of system. Different ecosystems and their constituent species play different roles in the maintenance of essential life-support processes, for example, energy conversion, biogeochemical cycling, and evolution (MA, 2003). Ecological measures of value (importance) are, for instance, integrity, ‘health’ or resilience, which are important indicators to determine critical thresholds and minimum requirements for ecosystem service provision (TEEB, 2010).

For socio-cultural benefits and values, biodiversity and natural ecosystems are a crucial source of non-material well-being for many people through their influence on mental health and their historical, national, ethical, religious, and spiritual values. Some ecosystem services are considered essential to a people’s very identity and existence. Socio-cultural values, however, cannot be fully captured by economic valuation techniques and have to be complemented by other approaches in order to inform decision-making. To obtain at least a minimum (baseline) measure of importance of socio-cultural benefits and values several metrics have been developed such as the Human Wellbeing Index (TEEB, 2010).

In economic terms, biodiversity and ecosystem services can be considered as contributing to different elements of 'Total Economic Value', which comprises both use values (e.g. direct use such as resource use, recreation, and indirect use from regulating services) and non-use values, e.g. the value people place on protecting nature for future use (option values) or for ethical reasons (bequest and existence values). The economic importance of most of these values can be measured in monetary terms, with varying degrees of accuracy, using various techniques including market pricing, shadow pricing and questionnaire based (TEEB, 2010).

Although the TEEB study focuses primarily on the measurement of economic values and the assessment of costs and benefits via a welfare economics approach, it also encompasses equity considerations in particular for the aggregation of benefits over time and over groups of people. It specifically analyses the relationships between ecosystems and poverty ('GDP of the poor'), because of the higher dependence of the poor on ecosystem services for their livelihood (TEEB, 2008).

(4) Governance and decision making

In governance and decision making process, the dilemma of how to balance ecological, socio-cultural and economic value commonly happens at any level (e.g. private, corporate or government). TEEB focuses on the economic, notably monetary, consequences of the loss of biodiversity; it concentrates on;

- aggregating monetary values,
- economic trade-off issues,
- systems of ecological-economic accounting: macro-economic implications,
- awareness raising and positive incentives.

Aggregation involves bringing together all the information on the monetary values of ecosystem services by ecosystem type into a single matrix to attain an aggregate monetary value of all delivered ecosystem services (TEEB, 2010). Key issues requiring consideration include;

- accounting for uncertainties in the monetary valuation of individual services,
- interdependencies between ecosystem services at the ecosystem scale,
- aggregation of values over individuals and groups of people,
- aggregation of values over spatial scales and (v) aggregation of values over time.

A trade-off occurs when the extraction of an ecosystem service has a negative impact on the provision of other services (TEEB, 2010). Timber extraction from a forest, for example, will affect, among others, vegetation structure and composition, visual quality and water quality which will hinder or at least affect the continuous provision of other services (e.g. wildlife harvesting, carbon sequestration, recreation) over time, since loss of structure implies loss of function, and consequently of other services and their derived benefits. Approaches to trade-off analysis include: multi-criteria (decision) analysis, cost-benefit analysis and cost-effectiveness analysis (TEEB, 2010).

Ecosystem services are needed to include in economic accounts in order to ensure that their contribution to well-being is recorded in the macroeconomic indicators. Ecosystem accounting, linked to geographical information systems and to socio-economic data, can offer a useful framework for systematically collecting and analysing data to support assessments of changes in the production and use of ecosystem services, taking into account their spatial heterogeneity (TEEB, 2010).

A growing number of governments recognize the need to include ecological importance (value) of ecosystems in decision making in order to ensure that decisions taken at various governmental levels do not lead to greater degradation of ecosystems and even improve their condition (TEEB, 2010). Raising societal awareness of the need for research and development, and for changes in policy, practice and law, are essential mechanisms for sustainable ecosystem management and resource use, and engage in eco-regional planning and large-scale restoration and rehabilitation of renewable and cultivated natural capital (Aronson et al. 2007).

(5) Scenarios and drivers of change

Ecosystems have always been dynamic, both internally and in response to changing environments. Using scenarios in ecosystem service assessments is important and should become the norm in ecosystem service research (TEEB, 2010). The generation of scenarios is particularly important for monetary valuation, since scenarios enable analysis of changes in service delivery which are required to obtain marginal values. Comparing the outputs under several scenarios will inform decision makers of the welfare gains and losses of alternative possible futures and different associated policy packages (TEEB, 2010). To elaborate each scenario, the likely consequences of drivers that directly affect the status, current management and future trajectories of ecosystems and biodiversity (and thus of the services and values they represent) must be analysed.

The lower left-hand boxes in Figure 3 show direct, indirect and external drivers for ecosystem change. *Direct drivers* can be divided in negative, neutral and positive categories. *Negative drivers* include, among others, habitat destruction, over-use of resources. *Neutral drivers* can have positive or negative consequences for ecosystems and biodiversity, depending on the context and management regime. Finally, *positive drivers* help enhancing natural capital but can have negative impacts on ecosystems and biodiversity, when applied in the wrong place or context, so the effects of any direct driver on ecosystems need to be carefully analysed. *Indirect drivers* of ecosystem change include demographic shifts, technology innovations, economic development, legal and institutional frameworks, including policy instruments, the steady loss of traditional knowledge and cultural diversity and many other factors that influence our collective decisions. These indirect drivers affect the way people directly use and manage ecosystems and their services (TEEB, 2010).

(6) Linking ecosystem service values to decision-making

Decision-makers at international, national, governmental, local authorities, companies and individuals, both public and private, affect drivers of ecosystem change via demographic, economic, socio-political, scientific and technological processes as well as cultural and religious factors, which in turn affect ecosystem services and human wellbeing (TEEB, 2010). Ecological importance (value) of ecosystems should be considered in concrete policies, instruments and measures (e.g., subsidies and incentives, environmental liability, market creation, national income accounting standards, trading rules, reporting requirements, eco-labelling), it aims to enhance biodiversity and ecosystem protection as a prerequisite for maintaining natural service levels.

Additionally, it is necessary to incorporate the values of ecosystem services in location-specific, cost-benefit and cost-effectiveness analysis, and their use in methods and guidelines for implementing payments for ecosystem services, as well as equitable access and benefit-sharing arrangements for genetic resources and protected areas. Business end-users need to be able to assess the business impacts on biodiversity and ecosystems, both for measuring and managing risks and identifying and grasping new market opportunities for private enterprises. Moreover, individuals and consumer organizations must also be addressed as they can significantly reduce population based impacts on wild nature while influencing producers through private purchasing decisions. This will include steps to improve consumer information on the land, water and energy resources used in producing foods and consumer goods.

2.6.5 Estimates of Monetary Values of Ecosystem Services

Within this total economic framework, the monetary values of ecosystem services provided by eleven biomes/ ecosystems are estimated by TEEB (2010). These include open oceans, coral reefs, coastal systems, coastal wetlands, inland wetlands, lakes and rivers, tropical forests, temperate and boreal forests, woodlands, grasslands, and polar and high mountain systems but exclude the desert and tundra biomes because too few data points were found on their services and values.

All values were converted into 2007 International Dollar values using the GDP deflators and purchasing power parity converters from the World Bank Development Indicators 2007 (TEEB, 2010). A preliminary overview of the range of monetary values for each ecosystem service, per biome, are presented only the minimum and maximum values which based on individual studies and sometimes leads to very wide value ranges. Therefore, the use of average values in benefit-transfer between locations must be done with great care and should be based on sustainable use levels.

(1) Monetary values of ecosystem services provided by open oceans

The open ocean is the largest area of the marine ecosystem, including deep sea (water and sea floor below 200m). Based on six data points, the total monetary value of the potential sustainable use of all services of open ocean combined varies between 13 and 84 $/ha/yr (TEEB, 2010).

(2) Monetary values of ecosystem services provided by coral reefs

The term 'coral reef' generally refers to a marine ecosystem where the main organisms are corals that house algal symbionts within their tissues (TEEB, 2010). Corals are often included in the 'coastal systems biome' but are dealt with here separately because of their unique and important ecosystem services. Based on 101 data points, the total monetary value of the potential sustainable use of all services of coral reefs combined varies between 14 and 1,195,478 $/ha/yr (TEEB, 2010).

(3) Monetary values of ecosystem services provided by coastal systems

The coastal biome includes several distinct ecosystems such as sea-grass fields, shallow seas of continental shelves, rocky shores and beaches, which are found in the terrestrial near-shore as well as the intertidal zones – that is, until the 200m bathymetric line with open oceans (TEEB, 2010). Based on 32 data points, the total monetary value of the potential sustainable use of all services of coastal systems combined varies between 248 and 79,580 $/ha/yr (TEEB, 2010).

(4) Monetary values of ecosystem services provided by coastal wetlands

The coastal wetlands biome includes two main types of ecosystem – tidal marshes and mangroves (TEEB, 2010). Based on 112 data points, the total monetary value of the potential sustainable use of all services of coastal wetlands combined varies between 1,995 and 215,349 $/ha/yr (TEEB, 2010).

(5) Monetary values of ecosystem services provided by inland wetlands

The inland wetlands biome includes (fresh water) floodplains, swamps/marshes and peat lands. Based on 86 data points, the total monetary value of the potential sustainable use of all services of inland wetlands combined varies between 981 and 44,597 $/ha/yr (TEEB, 2010).

(6) Monetary values of ecosystem services provided by lakes and rivers

This biome-type includes freshwater rivers and lakes (TEEB, 2010). Saline lakes, and wetlands and floodplains are not included in this biome. Based on 12 data points, the total monetary value of the potential sustainable use of all services of rivers and lakes combined varies between 1,779 and 13,488 $/ha/yr (TEEB, 2010).

(7) Monetary values of ecosystem services provided by tropical forests

This tropical forest biome includes various types of forests, for example moist- or rainforests, deciduous/semi-deciduous broadleaf forest and tropical mountain forests (TEEB, 2010). Based on 140 data points, the total monetary value of the potential sustainable use of all services of rivers and lakes combined varies between 91 and 23,222 $/ha/yr (TEEB, 2010).

(8) Monetary values of ecosystem services provided by temperate and boreal forests

This biome-type includes temperate and boreal forests, or taiga. Temperate forests can be subdivided into temperate deciduous forest, temperate broadleaf and mixed forest, temperate coniferous forest and temperate rainforests (TEEB, 2010). Based on 40 data points, the total monetary value of the potential sustainable use of all services of temperate and boreal forests combined varies between 40 and 4,863 $/ha/yr (TEEB, 2010).

(9) Monetary values of ecosystem services provided by woodlands

This ‘woodland-biome’ includes a large range of vegetation types including savannas, shrublands, scrublands and chaparral interleaved with one another in mosaic landscape patterns distributed along the western coasts of North and South America, and areas around the Mediterranean Sea, South Africa and Australia, jointly representing 5 percent of the planet’s surface (TEEB, 2010). Based on 18 data points, the total monetary value of the potential sustainable use of all services of woodlands varies between 16 and 1,950 $/ha/yr (TEEB, 2010).

(10) Monetary values of ecosystem services provided by grasslands

Grasslands occur in a wide variety of environment. They include tropical grasslands (savannas), temperate grasslands (including the European and Central Asian steppe and North American prairie, boreal grasslands (tundras) and mountainous grasslands (such as the Latin American Paramo highlands). The largest continuous stretch of tropical grassland is the North African Sahel, which stretches from Senegal to the Horn of Africa (TEEB, 2010). Based on 25 data points, the total monetary value of the potential sustainable use of all services of grasslands varies between 297 and 3,091 $/ha/yr (TEEB, 2010).

(11) Monetary values of ecosystem services provided by polar and high mountain systems

This biome is defined in term of its cryoshere. Polar regions include all the Arctic seas and much of the Southern Ocean, the tundra/permafrost zone to the tree line, areas where there is long-term snow cover (especially in the Arctic), and submarine zones in the Southern/Arctic oceans. High mountain regions could be defined as those areas higher than the 1000masl mean line (TEEB, 2010). There is currently very little qualification of the monetary value of services provided by polar and high mountain systems. The lack of monetary valuation research, however, should not be interpreted to infer that polar and high mountain areas do not deliver important services. It is clear that these cryospheres are of paramount importance in terms of global ecosystem services (TEEB, 2010).

2.7 Climate Change and Agriculture

Agriculture is an important economic sector, which produces food that contributes to the basic needs of people and is one of the major sources of rural livelihoods (Meridian Institute, 2011). The impacts of climate change on agriculture have been identified as potentially the most serious in terms of highly dependence on weather or climate, numbers of people affected and the severity of impacts on those least able to cope (Wreford et al., 2010). However, it is important to note that agricultural practices also impact on climate and agriculture is also one of the contributors of the of the greenhouse gases. According to the IPCC Fifth Assessment Report (2013), the major agricultural emissions including methane (CH_4) and nitrous oxide (N_2O) were 1803 ppb and 324 ppb which exceeded the pre-industrial levels by about 150%, and 20%, respectively. The massive increase in the number of ruminants, the emissions from fossil fuel extraction and use, the expansion of rice paddy agriculture and the emissions from landfills and waste, are the dominant sources that emit large amounts of anthropogenic CH_4. Anthropogenic emissions account for 50% to 65% of total CH_4 emissions (IPCC, 2013). The concentration of N_2O increased at a rate of 0.73 ± 0.03 ppb yr–1 over the last three decades (IPCC, 2013). The main anthropogenic source of nitrous oxide is soil and animal manure management but substantial contributions also due to sewage treatment, combustion of fossil fuel, and chemical industrial processes. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests (IPCC, 2013).

As the world's population is projected to increase to 9.6 billion people by 2050 and 10.9 billion by 2100 (DESA, 2013) and the rising demand on arable land for food and fuels productions, will require substantial increases in agricultural productivity in the context of more constrained availability of resources (Meridian Institute, 2011). In addition, agriculture contributes 29 percent of developing countries' gross domestic product (GDP) and provides employment to about 20 percent of the global population and 65 percent of developing countries' populations (Meridian Institute, 2011). Least developed countries in the tropical and subtropical areas are more vulnerable to climate change mainly due to their economic dependency on climate sensitive sector such as agriculture and fisheries and limited human, institutional and financial capacity to face the effects of climate change (Sem, 2009)

The agriculture sector, however, has great potential for synergies among mitigation, adaptation, food security and poverty reduction. Agriculture is highly site and context specific, thus, uniform strategies and solutions are ineffective. Technologies in one area may be synergistic while it may have a detrimental effect in another due to climate change (Meridian Institute, 2011). Further, Agriculture will bring complex links between the issues of climate change and food security as climate change will likely affect agricultural production, distribution and supply of food and alter food prices.

2.7.1 Climate Change Impacts on Agriculture

Agronomic research indicates that higher temperatures associated with climatic change threaten food production and supply. According to IPCC (2007), maize, wheat and other major crops have substantially declined at the global level of 40 megatonnes per year during 1981-2002 while grains experience yield reductions by about 5 percent due to each 1 degree Celsius of temperature increase. Additionally, climate change will have an effect on the water resource availability, which is the main input for agriculture. As water resources become scarce it will impact on the irrigation potential of the area and eventually affect agricultural production. Climate change also causes further adverse impact on agriculture by aggravating the increased incidence of pest and diseases favoured by the frequent drought, heat stress, and fast growing period as well as increased flooding (Maharjan and Joshi, 2013).

2.7.2 Site and Context Specification of Agriculture

As agriculture is highly site and context specific, its sensitivity to changes in climatic factors differs significantly from region to region. The impact of climate change on agriculture varies across the region over the world; some regions are benefiting from such changes while some regions are losing. It is estimated that overall impact of climate change on global agricultural GDP will be between −1.5% to +2.6% by 2080 with considerable regional variation (Fischer et al., 2002). For example, high latitude regions (which specially cover developed countries) are expected to benefit from increasing temperatures. Higher warming can expand the areas potentially suitable for cropping as well as the length of growing period and crop yields in the regions (Schmidhuber and Tubiello, 2007). Similarly, a moderate increase in temperature in some humid and temperate grassland may increase pasture productivity and reduce the need for housing and compound feed for livestock. Contrastingly, low-latitude regions (especially tropical developing countries) may be adversely impacted by the projected heat wave and drought increases. Therefore, some cultivated areas are expected to become unsuitable for cropping and some tropical grassland may become increasingly arid (Maharjan and Joshi, 2013).

2.7.3 Adaptation in Agriculture

Adaptation to climate change is typically identified as an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic factors and their effects and impacts, in order to alleviate adverse impacts of change or take advantage of new opportunities (Wreford et al., 2010). Adaptation is, however, a complex process as climate change has varying effects on different regions. Therefore, the risks and opportunities related to climate change will also depend from region to region, which is why it is crucial to do country-specific research for any adaptation measures on agricultural practices (Meridian Institute, 2011). Adaptation can involve both building adaptive capacity which increasing the ability of individuals, groups, or organisations to adapt to changing climate; and implementing adaptation decisions, i.e. transforming that capacity into action. Both dimensions of adaptation can be implemented in preparation for, or in response to, impacts caused by climate change (Wreford et al., 2010).

As noted by Tompkins and Adger (2004), the major types of adaptation include reducing the sensitivity of the affected system, altering the exposure of a system to the effects of climate change and increasing the resilience of social and ecological systems. First, reducing the sensitivity of the affected system can be achieved, for instance, by investing in flood defences or increased reservoir storage capacity; planting hardier crops that can withstand more climate variability; or ensuring that infrastructure in flood-prone areas is constructed to allow flooding. Second, altering the exposure of a system to the effects of climate change can be achieved, for example, by investing in hazard preparedness and early warnings, such as seasonal forecasts and other anticipatory actions. Finally, increasing the resilience of social and ecological systems can be achieved through generic actions which aim to conserve resources, but also include specific measures to enable specific populations to recover from loss.

2.7.4 Mitigation in Agriculture

Despite the agriculture sector being one of the contributors of the greenhouse gases, the sector has huge mitigation opportunities for reduction of greenhouse gases. Worldwide agricultural production offers an estimated mitigation potential of 5.5–6 Gt CO_2-eq yr^{-1} that is almost equal to its current total annual emissions of 5.1–6.1 Gt CO_2-eq yr^{-1} (Meridian Institute, 2011). The international climate change regime designed Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Forest Degradation (REDD) to help facilitate industrialized countries to meet their emission targets. Developing countries could be a part of it by fulfiling their dual purpose of fulfilling own responsibility of achieving sustainable development and at the same time earn income through carbon finance (Wreford et al., 2010).

The most challenging aspect of mitigation in agriculture is achieving it without compromising food security both nationally and globally (Meridian Institute, 2011). Increases in agriculture production naturally increases in GHGs from the sector as well. However, there is potential for mitigation by increasing efficiency in agriculture production and also through reduction in emission along with removal of carbon through sequestration in agricultural soils and biomass (Murphy et al., 2010). The mitigation options from agriculture can be broadly distinguished into seven categories including cropland management, grazing land management and pasture improvement, management of organic soils, restoration of degraded lands, livestock management, manure management, and bioenergy (Smith et al., 2007).

2.8 Conclusion

All countries are affected by the impacts of climate change, the poorest countries and populations suffer earliest and most. The costs of extreme weather, including floods, droughts and storms, are already rising, including for rich countries. If no action is taken, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever, but the cost of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year (Stern, 2007). Climate change is a global problem, thus the response to it must be international (Stern, 2007).

There is nowadays a growing level of awareness of the importance of ecosystems and biodiversity to human welfare. Information about the monetary importance of ecosystem services is a powerful and essential tool for decision-makers at various levels to make better, more balanced decisions with respect to their responsibilities in safeguarding biodiversity. In the past few decades, there have been attempts to estimate the economic value of ecosystem services. For the entire biosphere, the value was estimated to be in the range of $16-54 trillion

(10^{12}) annually, with an average of $33 trillion per year (Costanza et al., 1997). In addition, the monetary values of ecosystem services provided by 11 main biomes/ ecosystems such as open oceans, coral reefs, coastal systems, coastal wetlands, inland wetlands, lakes and rivers, tropical forests, temperate and boreal forests, woodlands, grasslands, and polar and high mountain systems have been recently estimated by TEEB (2010).

Agriculture is an important economic sector which supplies food for the basic needs of people and is one of the main sources of rural livelihoods (Meridian Institute, 2011). The impacts of climate change on agriculture have been considered as potentially the most severe in terms of numbers of people affected and the severity of impacts on those least able to cope (Wreford et al., 2010). The impact of climate change on agriculture varies across the region over the world; some regions are benefiting from such changes while some regions are losing. Agriculture, however, has great potential for synergies among mitigation, adaptation, food security and poverty reduction.

Chapter 3

Socio-Economic and Natural Resources Development in Northeast Thailand

3.1 Introduction

The purpose of this chapter is to provide an overview of the development background for NE Thailand and the recent knowledge about climate change in this region. This chapter begins by providing an overview of Thailand from a political and administrative system, geographical profile and national development background. The Philosophy of Sufficiency Economy, summary of the Eleventh National Economic and Social Development Plan (2012-2016). Bringing the focus to socio-economic and natural resources development in NE Thailand, the regional economic and social development plan is outlined. The chapter continuously reviews NE Thailand physical features, the regional development situations, and NE Thailand Regional Development Plan (2012-2016). Finally, the chapter examines the review of literature on NE Thailand and climate change and indicates the knowledge gap for this thesis.

3.2 Overview of Thailand

Located slightly over the equator, Thailand is in the Southeastern Asia region, covering an area of 513,115 km^2 (NESDB, 2006a). The country is divided into four natural regions: the mountainous north, the fertile central plains, the semi-arid plateau of the northeast, and the peninsular south. Thailand is a warm and rather humid tropical country with a monsoon climate. Average temperatures are about 29°C (17°C-35°C). In most of the country, there are three seasons: the winter season (November to February), the dry season (March to May), and the rainy season (June to October) (NESDB, 2005).

Figure 3.1 Map of Thailand

Source http://www.gms-eoc.org/uploads/map/archives/map/THA-Overview_5.jpg

In 2012, there were totalled 76 provinces, 878 districts, 7,255 sub-districts, and 74,956 villages (Department of Provincial Administration; DOPA, 2012a) with total population of 64.5 million (DOPA, 2012b). Metropolis Bangkok is divided into 50 municipal limits and governed by directly elected governor. Thai is the national language. More than 90% of the population is Buddhist (NESDB, 2006a). The literacy rate in Thailand is 98% (UNICEF, 2013). Income per capita in 2011 was THB 164,512 per year (NESDB, 2013c) or $5,395 per year (Bank of Thailand; BOT, undated). People working in the eastern part of Thailand earned the highest annual income of THB 436,479 ($14,313) while the northeastern people earned the least income of THB 48,549 ($1,592) per year (NESDB, 2013c). This accounted for the nine times difference in income per capita between the regions.

3.2.1 National Development Background

Formerly known as, "the National Economic Council," the National Economic and Social Development Board (NESDB) has been established since February 15th, 1950 to advise the government on economic issues (NESDB, 2006b). With the suggestions of the World Bank experts, soon after, the organisation was restructured as the central agency responsible for formulating national development plans. Subsequently, Thailand's first five-year National Economic Development Plan was launched in 1961 as a framework for the country's development (ONEP, 2011). This office is under supervision of the Office of the Prime Minister. In 1972, social development planning has been fully integrated into the economic plans (NESDB, 2006a).

From the first to the seventh National Development Plan, the country's economy improved dramatically. However, it has been argued that this development has led to unsustainable development and negative consequences for society (UNDP, 2007; NESDB, 2011a). These problems brought about a significant shift in Thailand development planning since the Eighth Plan (1997-2001), a shift from a growth-oriented approach to the new model of holistic "people-centred development", in order to ensure more balanced development across economic, social and environmental dimensions (NESDB, 2011b). However, performance was hindered by the 1997 Asian economic crisis. While the country was facing the difficult circumstances related to the crisis, the Philosophy of Sufficiency Economy was introduced by King Bhumibol Adulyadej as the guiding philosophy for the country's development and administration (NESDB, 2011a).

3.2.2 Sufficiency Economy: A Principle of Development

The Sufficiency Economy highlights the importance of national balanced development, which aims to enable the country to modernise in line with the forces of globalisation while shielding the nation against inevitable shocks and excesses that may rise from extensive and rapid socioeconomic, environmental and cultural changes (UNESCAP, 2006). In this instance, 'sufficiency' means moderation, reasonableness, and the need of self-immunity for sufficient protection from impact arising from internal and external changes' (Piboolsravut, 2004). To achieve this, it is necessary to apply knowledge with appropriate consideration and prudence; at the same time it is essential to strengthen the moral fibre of the nation. Meanwhile, a way of life based on patience, perseverance, diligence, wisdom and prudence is essential for creating balance and ability to cope appropriately with critical challenges emerging from rapid economic and cultural transitions (NESDB, 2007). Figure 3.2 presents the Philosophy of Sufficiency Economy.

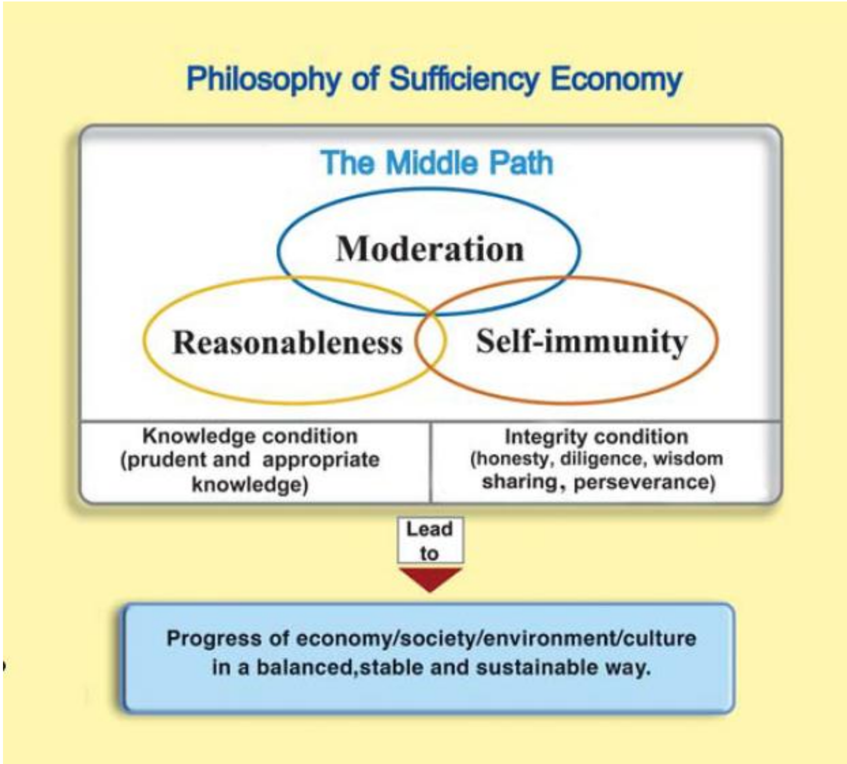


Figure 3.2 Philosophy of Sufficiency Economy (NESDB, 2007)

Agriculture is an important sector where the Philosophy has been incorporated into every social unit from the individual farmer and farm family to the community and country (NESDB, 2011a). King Bhumibol has been seeking ways to help the people engaged in agriculture; in 1992 His Majesty introduced the New Theory Agriculture. According to the theory, an average household size in Thailand is about 15 rais (2.4 hectares) area of land and is divided into four parts with a ratio of 30:30:30:10. Based on this ratio, 30% of land, approximately 0.48 hectares, is set aside for rice cultivation, the next 30% for growing fruit and perennial trees, the third 30% for fish culture, and the remaining 10% or 0.32 hectares for housing, raising animals and other activities (Piboolsravut, 2004).

The Philosophy of Sufficiency Economy can be applied not only in agricultural practices but also in, for example, government, financial, business and education sectors (NESDB, 2007). The key elements of the Philosophy were implemented in the development of the Eleventh National Plan. First, "reasonableness" was adopted in analytical work; "moderation" was exploited to generate a balance between material and spiritual aspects, between societal self-dependence and global competitiveness, and between rural and urban societies; "resilience" was applied to strengthen risk-taking ability in order to counteract internal and external changes (NESDB, 2011a). The national development process has to be governed by knowledge using a prudent, step-by-step approach, and correspond to the way of life desired in Thai society including moral values, a sense of virtue, ethics and perseverance in work and in the way of life, in order to prepare family, community, society, and the nation for both internal and external changes (NESDB, 2011a).

3.2.3 The Eleventh National Economic and Social Development Plan (2012-2016)

In the Eleventh Plan NESDB (2011a) highlighted that Thailand's future will be challenged by many significant and unpredictable global and internal changes such as the adjustment in global rules and regulations in world economic management, regional economic integrations, ageing society, food and energy security and the decline in the country's competitiveness. In addition, climate change and degrading natural resources and environment have exacerbated problems particularly in agricultural production and poverty while management of natural resources and the environment has not been effective. It is unequivocal that effective development strategies are essential for Thailand (NESDB, 2011b).

The vision of the Eleventh Plan is to create ‘a happy society with equity, fairness, and resilience’ where people have lived peacefully, been well-prepared for changes, within the society that has firm social foundations, quality economic growth, sustainable natural resources and environmental management, and good governance (NESDB, 2011a). The Eleventh Plan (NESDB, 2011a) has six development strategies including:

- Strategy of promoting the just society;
- Strategy of developing human resources to promote a life-long learning society;
- Strategy of balancing between food and energy security;
- Strategy of creating the knowledge-based economy and enabling environment;
- Strategy of strengthening economic and security cooperation in the region;
- Strategy of managing natural resources and environment towards sustainability.

3.2.4 Regional Economic and Social Development Plan

The Regional Economic and Social Development Plan has been formulated as the key basis tool in order to effectively link the National Plan to other related plans at the lower administration levels (NESDB, 2011a). The aim of the Regional Plan is directing the spatial development strategies with regarding their local potentials, connecting with the Eleventh Plan and following the Philosophy of the Sufficiency Economy to balance the regional development in various dimensions such as physical, economy, social and environment; and to enhance their resilience to external environment and internal situation changes (NESDB, 2011a; NESDB, 2011c). Each region in Thailand has to determine its roles and directions of development which consistent with its local potentials and external opportunities and encourage the sustainable development under the Eleventh Plan.

The Regional Plan is implemented as guidance for Provincial/Cluster Development Plan and the Annual Operation Plan of Provinces and Clusters in each region through annual budget allocation to support development projects. Besides, Ministries, Departments and Development Partners may conduct their plans and projects in the same direction of the Regional Plan in promoting and supporting the cooperation to drive the Eleventh Plan.

3.3 Socio-Economic and Natural Resources Development in NE Thailand

3.3.1 Physical Features:

NE Thailand is a rolling plateau, called the northeast plateau. It is about 200-

300m above sea level, covering a land area of 168,854 km^2, or approximately one third of the country (NESDB, 2003) making it the second biggest region in Thailand behind the North. This region is divided into 20 provinces, i.e. Khon Kaen, Udon Thani, Loei, Nong Khai, Mukdahan, Nakhon Panom, Sakon Nakhon, Kalasin, Nakhon Ratchasima, Chaiyaphum, Yasothon, Ubon Ratchathani, Roi Et, Buri Ram, Surin, Maha Sarakham, Si Sa Ket, Nong Bua Lam Phu, Amnat Chareon and Bueng Kan, which has been recently established by the Act Establishing Changwat Bueng Kan, BE 2554 (2011). There are 322 districts, 2,678 sub-districts, and 33,099 villages within the region (NESDB, 2011c).

Figure 3.3 Map of Northeast Thailand (Google Map)

The Northeast plateau consists of two main plains which are separated by the Phu Phan Mountains; first, the northern Sakon Nakhon plain is drained by the Loei and Songkhram Rivers and second, the southern Korat plain is drained by the Mun and Chi Rivers. The Mun River is the Mekong's main Thai tributary. It rises in the Khao Yai National Park near Nakhon Ratchasima province and runs east, joining the Mekong in Ubon Ratchathani province. The other main river in Northeast is the Chi River, which flows through central part of the region before turning south to meet the Mun in Si Sa Ket province. The smaller Loei and Songkhram Rivers are also tributaries of the Mekong, the former flows north through Loei province while the latter flows east through Udon Thani, Sakon Nakhon, Nakhon Panom and Nong Khai provinces. There are three main river basins in the region, i.e. Kong-Isan Basin (46,460 km^2), Chi Basin (49,476 km^2) and Mun Basin (69,700 km^2) (Department of Water Resource; DWR, 2010).

Figure 3.4 Three River Basins in Northeast Thailand (DWR)

According to Thai Meteorological Department (2010), the climate of the Northeast is dominated by both the southwest and northeast monsoons. The average temperature range is from 24°C to 29°C. The extreme lowest temperature recorded was -1.4°C at Sakon Nakhon Agrometeorological Station, the highest 43.9°C in Udon Thani. Average annual rainfall is about 1,370 mm and annual rainy days are about 117 days (TMD, 2010). The total volume of water from rainfall annually is approximately 227,580 Mm^3 (DWR, 2010). It is estimated that about 77% of the rainfall input is either loss through evapotranspiration or passed to ground water, whilst the remaining 23%, 51,565 Mm^3, becomes rivers and streamflow: 20,644 Mm^3 in the Kong-Isan basin, 11,948 Mm3 in the Chi basin, and 18,973 Mm^3 in the Mun basin (DWR, 2010).

In 2012, the Northeast had a population of 21.7 million accounted for 33.7% of the country's total population (DOPA, 2012b). There were males and females of 10.8 and 10.9 million, respectively. The Northeast has contributed the most labour forces in the country compared with other regions. There were 12.7 million or 34.1% of Thailand's total labour forces and most of these labours, 53.4%, work in agriculture sector while the rest work in manufacture and service sectors (NESDB, 2011c).

3.3.2 The Northeast Regional Development Situations

Known locally as Isan, NE Thailand is in many ways distinct from other parts of the country (Maneenetr, 2007). Isan's culture has much in common with that of the nearby countries including Lao People's Democratic Republic (Lao PDR), Cambodia and Vietnam. NE Thailand is the most traditional part of the country and locals preserve their indigenous knowledge as part for their daily lives, thus generating an important source of income for the families and contributing significantly to the economy (TAT, undated b). NE Thailand economy is small and has had limited economic expansion. According to NESDB (2013c), in 2011 the gross regional product (GRP) at current market prices was THB 1,114,945 million ($36,562 million), contributing 10.03% of the country's gross domestic products (GDP) of THB 11,120,518 million ($364,674 million). Agriculture, manufacturing and trade are the major economic sectors accounted for 21.69%, 20.19% and 10.63% of GRP, respectively. NE Thailand plays a leading role in the domestic agricultural productions, however, its productivity is low (NESDB, 2011c). Income per capita of NE Thailand people is the least in the country (NESDB, 2013c) and an average annual income of NE Thailand farmer in 2009 was THB 12,824 ($373.5) per year, less than half of the average farmer's income in Thailand (NESDB, 2011c).

With regard to its demographic structure and consistent with the nation's population structure changes, NE Thailand is becoming an ageing society (NESDB, 2011c). An increase in the proportion of the population that are elderly and a decrease in the younger population and workforce have resulted in lower labour productivity and potentially on increase future public expenditure (NESDB, 2011a). Besides, NE Thailand society has experienced more problems in family and life insecurity (NESDB, 2011c). For example, violence has prevailed when conflicts have arosen within the family. More children have been neglected since more parents have divorced (DOPA, 2013). Thus, in recent years, an increase in criminal cases, especially illegal drug arrests have been reported (NESDB, 2011a; NESDB, 2011c). Furthermore, although the government provides free education through upper secondary school to all Thais, NE Thailand labour force is poorly educated, especially farmers (NESDB, 2011c). Most farmers graduate with primary school education. They have to leave school early for farm works. Moreover, some disadvantaged groups have lacked access to social services (NESDB, 2011c).

In 2011, agricultural land covered 102,156 km^2 or 60.5% of the regional area while non-agricultural land had covered 39,141 km^2 or 23.2% of the total land area (OAE, 2013). Irrigated land covered 13,760 km^2 (DWR, 2010) and accounted for only 8.1% of the total land area or 13.5% of the agricultural land. In addition, soil in the region is mostly sandy and infertile. There are substantial deposits of underground potash and rock salt, resulting in a large proportion of saline soil which unsuitable for cultivation (NESDB, 2011c). Sandy soil retains very little water; therefore, a deficiency in water supply is the main problem of the region (Sneddon, 2003; NESDB, 2011c).

NE Thailand is located in the Lower Mekong River Basin. Rice is the most important agricultural product of the region in terms of the ratio of land area used, the quantity and value of output, and contribution to people's subsistence as the main diet (Chinvanno, 2008a). In 2011, NE Thailand rice cultivation covered 68,412 km^2 and accounted for 67.0% of the total regional agricultural area or 61.1% of the country's total paddy fields (OAE, 2013). Most rice is grown under rain-fed conditions as the irrigated land area is limited, accounting for 13.5% of total agricultural area (DWR, 2010; OAE, 2013).

3.3.3 The Northeast Regional Development Plan (2012-2016)

NESDB (2011c) designates the NE Thailand's role within the national economy as the domestic producer of food and renewable energy crops; industrial manufacturer; Indochina gateway; and archaeological, Khmer civilisation, cultural and natural attractions.

NE Thailand is a major agricultural base for production of food and renewable energy sources of the country. The regional agricultural land accounts for 42.8% of the country's agricultural land area (OAE, 2013). Main agricultural commodities are rice, cassava, sugar cane and maize; these products are mainly used as raw materials for food and ethanol manufacturing in the region. NE Thailand is the largest producer of rice and cassava in Thailand, and provides up to half of domestic productions (OAE, 2012). With regard to renewable energy, there are currently 18 ethanol factories operating across the region with total capacity of 4.8 million litres per day, accounting for approximately 40% of total domestic productions (NESDB, 2011c).

In addition, the region is beginning to emerge as the country's manufacturing hubs for electronics, automobiles and electrical appliances. The major supporting factors of the shift of the production bases from the Central and Eastern regions to the Northeast are mainly due to the improvement of transportation networks and abundance of labour forces in the region with the attendant low cost of production (NESDB, 2011c).

NE Thailand can accomplish and take advantage from the economic cooperation with neighbouring countries under the Greater Mekong Subregion (GMS) Economic Cooperation Program. In 2012, member countries of the GMS agreed to draw up a $50 billion pipeline of potential projects under a new Regional Investment Framework (RIF), including investments in railways, power supply, agricultural programme and environment programme biodiversity conservation corridors initiative to be made over the next decade (ADB, 2013). Ensuring preparedness to response to these developments, NE Thailand is constructing customs checkpoints, border economic centres, and border crossing facilitation in border cities including Mukdahan, Nong Khai, Nakhon Panom and Ubon Ratchatani provinces (NESDB, 2011c).

3.4 The Northeast and Climate Change

Recent weather disasters in Thailand include not only the worst widespread flood in 2011 (which was the worst floods in more than half a century (World Bank, 2012a)) and the worst drought in 2010. The drought was the worst in 20 years, resulting in the water level of the Mekong River falling to its lowest level in 50 years (Marks, 2011). The droughts adversely affected 15.7 million people in 64 provinces, total damage and losses approximately THB 1,415.22 mllion ($44.6 million) (Chariyaphan, 2012).

The Eleventh National Plan highlights climate change as a key component that influences future national development (NESDB, 2011a). As NE Thailand is the poorest region of the country, millions people live below the $2-a-day poverty line (NESDB, 2013a) and its economic structure is based on its natural resources, with a high proportion of its population working in the agricultural sector, NE Thailand is confronted with the severe impacts of climate change (NESDB, 2011c). With limited adaptability, the poor in the Northeast are at risk to the impacts of climate change. If no action is taken, poverty will be extensive. Therefore, NE Thailand needs to move forward to be prepared for adapting to climate change.

Over the last decade, there has been an increasing attempt to study the future climate change impact on water resources and rain-fed agriculture production in the countries of the Mekong River region as they are concerned as the most significant sectors vulnerable to climate stresses in the region (Chinvanno and Snidvongs, 2005). Rain-fed agriculture is the dominant economic activity of the region, engaging a high proportion of the population (Schiller et al., 2001; UN-ESCAP, 2006). Data from long-term climate projection scenarios can be applied to assess impact of climate change in various sectors and support long-term planning, especially climate change adaptation planning (Chinvanno, 2003). Understanding the impact of future climate change would assist the country to cope with future impact and minimise the potential vulnerability that may occur to various social groups (Chinvanno and Snidvongs, 2005).

Impact of Climate Change and Carbondioxide fertilisation effects in NE Thailand

In 2005, Snidvongs et al. (2005) examined climate change scenarios and impact on water resources in major watershed in Lao PDR and Thailand. The study demonstrated that climate scenarios in Lao PDR and Thailand indicate that the region in general is expected to be slightly warmer and possibly wetter when the atmospheric CO_2 is raised to 540 ppm. On average over the region, the daily maximum temperature would be changing by ±0.5 °C. More cloud could affect some simulated ‘cooling’ in the region. When the CO_2 is further elevated to 720 ppm, most of the region is expected to be significantly warmer by about 1 °C relative to the baseline period (CO_2 concentration at 360 ppm). It is anticipated warmer in the night time especially during the cool period of the year (Dec-Jan-Feb) and the number of cool days should be significantly less. Areas nearby the coast are expected more increased rainfall.

In addition, the study also conducted the hydrological analysis using Variable Infiltration Capacity (VIC) hydrological model, a macro-scale hydrologic model that solves full water and energy balances, on selected 3 major watersheds in Lao PDR and Thailand as case study: Nam Ngum and Nam Thuen watersheds in Lao PDR and Chi-Mun watershed in Thailand. The analysis showed the result in higher discharge from all 3 watersheds in the future under influence of climate change. This may due to increasing of annual precipitation in the region.

A further study which set out to determine potential impact of climate change on maize, sugarcane and cassava production in Khon Kaen province, NE Thailand, Sarawat et al. (2005) found that climate change increased maize and sugarcane yield in Khon Kaen but decreased for cassava. The different scenarios of CO_2 conditions generated by the Conformal Cubic Atmospheric Model (CCAM) models were used as inputs at 1.5-2.0x present CO_2 and showed that maximum temperature increased by 1-2°C while precipitation increased by 9-16% when compared to present. The effect of “with” and “without” fertilizer application was determined separately. Sarawat et al. (2005) pointed out that applying fertilizer could reduce the fluctuation of impact and even reduce 2-4 anthesis days and 3-10 maturity days.

The study of impacts of climate change on KDML105 rice (Jasmine rice) production in Kula Ronghai Field carried out by Kerdsuk et al. (2005). The study applied simulated weather data from the CCAM climate model, which cover three periods: baseline year (1xCO_2, 1980-1989), 1.5xCO_2 (2040-2049), and 2.0xCO_2 (2066-2075). The results showed that CO_2 fertilisation have positive impact on KDML105 rice yield in Tung Kula field in the future. The rice yield is higher under climate condition at CO_2 when CO_2 increase to 1.5 time and 2 times, with little deviation from year to year under each period. Kerdsuk et al. (2005) highlighted that changed planting date from 1 June to 15 May shows significantly reduction in KDML105 rice yield.

Another study of impacts of climate change on KDML105 rice production conducted in Sakonnakorn province by Buddhaboon et al. (2005), using the same scenarios as the former study, found inconsistency regarding the CO_2 fertilisation effect. The study reported that the rice yields were not significant difference between the 1.0xCO_2 (baseline year), 1.5xCO_2 and 2.0xCO_2 scenarios.

Kerdsuk et al. (2013) studied on risk, vulnerability and adaptation of agriculture system and rain-fed farmer sub-sectors to impact of climate and socio-economic change: case study in Chi-Mun river basin. The study projected crop yields of four major crops; i.e. rice, maize, cassava and sugar cane in Chi and Mun river basins in the case of business as usual under the impact of climate change and CO_2. The study showed the reductions of cassava and maize yields while rice and sugar cane yields are insignificant changes.

Table 3.1 Projection of crop yields in Chi and Mun river basins in the case of business as usual under the impact of climate change (Million tonnes)

Crops	1995-2004	2010s-30s		2040s-60s		2070s-90s	
Rice	12.23	12.12	-0.9%	12.26	0.2%	12.92	5.6%
Cassava	27.53	26.78	-2.7%	23.56	-14.4%	20.4	-25.9%
Sugar Cane	28.81	28.61	-0.7%	28.28	-1.8%	29.44	2.2%
Maize	1.31	1.19	-9.2%	1.07	-18.3%	1.01	-22.9%

Source Kerdsuk et al. (2013)

A study of strategies for managing climate risks in the lower Mekong River basins: a place-based approach by Chinvanno et al. (2008b) was conducted through household interview and focus group meeting in farm communities of the Vientiane Plain and Savannakhet province in Lao PDR, Kula Field and Ubon Ratchathani province in Thailand, and the Mekong River delta area in Vietnam. The study highlighted that prolonged midseason dry spells coming after sowing rice seeds or transplanting seedlings and flooding near the end of the crop cycle before harvest time are concerns by farmers in the region as the most significant climate phenomena threat to their livelihoods.

Chinvanno et al. (2008b) stated that rice farmers in NE Thailand exploited household and national-level measures for reducing climate risks but declined the community-level measures. The household measures focused on income diversification, primarily seasonal migration to work in the cities. Other practices include cultivation of new rice varieties that are both accepted in the market and more resistant to stress, changing in seedling technique, using hired machinery, growing alternative crops between rice seasons and feeding livestock, constructing small-scale irrigation systems, building embankments to prevent flood damage, and implementing mix-farming practices.

In addition, national policies and measures that are aimed mainly at poverty reduction, and simultaneously serve to reduce vulnerability to climate hazards, include financial support to farmers, rural infrastructure development, supporting transition to other crops and more diversified farming system, supporting marketing of village products, research and development of new seed varieties, and provide information for farm management including seasonal climate forecasts (Chinvanno et al., 2008b).

A recent study on the impact of climate change on agricultural revenue and adaptation strategies of farmers in Northestern Thailand by Khamwong and Praneetvatakul (2011), found that increased temperature in summer and early rainy season declines farm net revenue in NE Thailand, while increased rainfall in summer and early rainy season on the other hand would lead to growing farm net revenue, an increase in rainfall at the end of the rainy season will affect farm net revenue negatively. Adapting strategies to climate change adopted by farmers in both irrigation and rain-fed areas include (i) soil and land management i.e. cover crop planting to increases soil moisture, crop diversification, utilisation of organic fertilizer, changing planting dates, changes in crop varieties, etc., (ii) water resource management, i.e. digging a small water storage in farm and developing a drip irrigation system, etc., and (iii) labour management by off-farm employment.

Additionally, the study of mainstreaming climate change into community development strategy in Lao-oi district, Kalasin Province, Thailand (Chinvanno, 2011) demonstrated the way climate change is mainstreamed into local development plans. As the main livelihood of the community is rain-fed, wet season rice farming and located in lowland area between 2 rivers, the Lum-pao River and the Chi River, the major climate threat that the livelihood of the community is flooding, which occurs in late rainy season during the month of October - November. Farmers of Lao-oi district planned to switch from rain-fed wet-season rice farming to irrigated-dry-season rice farming, which is based on pump systems that pump water from river stream and feed water through underground pipe system to rice field, to fully cover the rice paddy area in the district. Such a strategy will change the risk and vulnerability profile of the community completely. Farmers of Lao-oi district will no longer be exposed to flooding but exposed to heat stress and potential water shortage instead, if water cannot be pumped from river to feed paddy area.

During the past 10 years, studies conducted in NE Thailand (e.g. Buddhaboon et al., 2005; Kerdsuk et al., 2005; Sarawat et al., 2005; Snidvongs et al., 2005;

Chinvanno et al., 2008b; Chinvanno, 2011; Khamwong and Praneetvatakul, 2011) mainly focused on the future climate change impact on main crops including rice, cassava, sugarcane and maize as well as impact on water resources and investigated how the farmers in the region adapt to climate change. However, there are other economic crop cultivations in NE Thailand such as para rubber, soybeans, goundnuts, mungbeans, shallot, garlic, potato, kenaf, cotton, longans, pineapples, oranges, and durians. In particular, para rubber is growing in market demand and planted areas (Chula Unisearch and SEA START RC, 2012). Planted areas of para rubber have increased drastically from 79.8 hectares in 1989 to 5,946.7 hectares in 2010 (OAE, 2012). There is no research in NE Thailand that attempts to study the future climate change impact on main crops (rice, cassava, sugarcane and maize) including other economic crops (para rubber, soybeans, goundnuts, mungbeans, shallot, garlic, potato, kenaf, cotton, longans, pineapples, oranges, and durians).

Policymakers in Southeast Asia including Thailand pay greater attention to adaptation to climate change as it is believed that future climate change would bring immense impact to the region where people are considered highly exposed to climate risk (Chinvanno, 2011). Unfortunately, the most literature on NE Thailand examined autonomous adaptation to climate change adopted by farmers in the region. To develop adaptation measures and policies for climate change impacts on the agriculture sector in NE Thailand, however, policymakers need to understand importance of climate change knowledge and to incorporate the climate change issues into future development plan (Chinvanno, 2003), especially transformational changes which can support farmers in the region to cope with climate variability and change in extreme weather event, for instance, the integrated water resources management. Moreover, integrating climate change adaptation plans into socioeconomic development plans could underpin the achievement of long-term development goals under future climate patterns (Chinvanno, 2011).

The central aim of this thesis is to examine the impact of climate change on net revenue of farmers in NE Thailand regarding the cultivation of all economic crops in the region, i.e. rice, cassava, sugarcane, maize, para rubber, soybeans, goundnuts, mungbeans, shallot, garlic, potato, kenaf, cotton, longans, pineapples, oranges, and durians, and to develop planned adaptation options or strategies for the agriculture sector in NE Thailand.

Chapter 4

Methodology

4.1 Introduction

Studies on the economic impact of climate change on agriculture conventionally start with understanding the patterns of variability of current and projected climate in order to carry out an analysis of the impact of future climate change (Chinvanno and Kerdsuk, 2013). This study utilises this conventional approach to estimate the economic impact of climate change on agriculture in NE Thailand. The aim of this chapter is to provide an overview of methods and datasets used throughout this thesis. The remainder of this chapter is comprised as follows: section 4.2 presents an overview of future climate scenarios for Thailand including climate change scenarios for NE Thailand; section 4.3 introduces methods to measure the economic impact of climate change on agriculture; section 4.4 demonstrates the Ricardian model specification; section 4.5 discusses on adaptation and managing risks in agriculture and finally, section 4.6 provides the details of a comprehensive province-level dataset used in this study.

4.2 Climate Change Scenarios for Northeast Thailand

Climate change is a slow and complex phenomenon and so in order to correctly detect the direction, magnitude and change in future climate pattern, long-term climate projections are needed (Chinvanno, 2009). To assess the impact of climate change in agriculture as well as to support long-term planning, long-term climate scenarios for each region of Thailand are required.

A range of long-term Greenhouse Gases (GHGs) emission scenarios were developed in 1990 and revised in 2000 in the IPCC Special Report on Emissions Scenarios (SRES, 2000). These scenarios reflected alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios were grouped into four scenario families: A1, A2, B1 and B2. The A1 storyline assumed a very rapid global economic growth with peaked population in the mid-century and rapid emergence of new and more efficient technologies. A1 was divided into three groups by directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 described a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 assumed an intermediate population and economic growth, emphasising local solutions to economic, social and environmental sustainability. A2 described a very heterogeneous world with high population growth, slow economic development and slow technological change. These SRES scenarios were widely adopted in the analysis of possible climate change, its impacts, and options to mitigate climate change (SRES, 2000).

In the IPCC Fifth Assessment Report (2013), the scientific community defined four new scenarios, called Representative Concentration Pathways (RCPs). They are identified by their approximate total radiative forcing in year 2100 relative to

1750: 2.6 W m^{-2} for RCP2.6, 4.5 W m^{-2} for RCP4.5, 6.0 W m^{-2} for RCP6.0 and 8.5 W m^{-2} for RCP8.5 (IPCC, 2013). These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6.0), and one scenario with very high greenhouse gas emissions (RCP8.5). The RCPs can thus represent a range of 21st century climate policies, compared to the no-climate-policy of the SRES used in former assessment reports (IPCC, 2013).

As the RCP scenarios have only been released recently, there has been no set of RCP scenarios for Thailand developed to date. As such, all future climate scenarios for Thailand were defined using IPCC SRES only and developed at high resolution using downscaling for local scale impact assessments. Firstly, for example, is the future climate scenario developed by the Southeast Asia Regional Centre of the Global Change **S**ys**T**em for **A**nalysis, **R**esearch and **T**raining Network (SEA START RC) which simulates the future climate in Thailand and surrounding countries based on the PRECIS (Providing REgional Climates for Impacts Studies) regional climate model and using the Global Circulation Model (GCM) ECHAM4 dataset as initial data for calculation covering IPCC emission scenarios A2 and B2 at a high resolution of grid size 20x20 km for the period of 2010-2099 (SEA START RC, 2010).

Secondly, is the future climate scenario developed by Department of Physics, Faculty of Sciences, Chiang Mai University which covers future climate projection for Southeast Asia including Thailand during period 2045-2054 based on the Weather Research and Forecasting (WRF) model for regional climate simulations at 60-km horizontal resolution using the fifth-generation atmospheric general circulation model (ECHAM5) developed at the Max Planck Institute for Meteorology (ECHAM5-WRF) and output from an IPCC SRES A1B scenario was used for future climate projection (Chotamonsak et al., 2011).

Thirdly, is the future climate scenario developed by the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi. This scenario projects future climate for Thailand during period 2030-2070 (SEA START RC, 2010) based on dynamic downscaling of ECHAM5 GCM, A2 and B2 scenarios, using the Regional Climate Model (RCM) version 3 from the Abdus Salam International Centre for Theoretical Physics (ICTP) with specified resolution of two domains: mother domain (D1) with a 60-km horizontal resolution covering the entire Indochinese Peninsula, parts of South China and South Asia and nested domain (D2) with a 20-km resolution covering Thailand, Laos, Cambodia, parts of Vietnam and Myanmar (Torsri et al., 2013).

Fourthly, there are the climate scenarios developed by Faculty of Sciences, Ramkhamhaeng University which covers future climate projection for Thailand during period 2010-2029 and 2040 – 2059 based on statistical downscaling technique using GDFL-R30 GCM, A2 and B2 scenarios, from Geophysical Fluid Dynamic Laboratory, National Oceanic Atmospheric Association (NOAA), USA, at resolution of 50km grid size (SEA START RC, 2010).

To study on the economic impact of climate change on agriculture in NE Thailand through determining how changing climate variables including temperature and precipitation are impacting the farmers’ income in the region, the climate change scenarios developed by the SEA START RC were selected. It mainly dues to the temporal coverage of these climate change scenarios , 2010-2099, which coincide same period of the climate change projections in this study, as well as their convenient accessibility that enable researchers to download climate scenarios from the SEA START RC website. They also provide future climate information on the geographical region of NE Thailand at high resolution of 20x20 km. As stated by Chotamonsak et al. (2011), high resolution RCMs perform better than coarse resolution GCMs in climate change projections particularly for variables that depend highly on regional topography such as precipitation, surface wind and temperature. In addition, the climate change scenarios developed by the SEA START RC are broadly applied in other projects of the Greater Mekong Subregion (Krittasudthacheewa et al., 2012).

Since climate projections contain uncertainty, it seems to be risky to adopt only one climate change scenario dataset to forecast the future climate for NE Thailand in this study. However, the climate change scenario for Thailand dataset developed by the SEA START RC is the only one that allows public accessibility. Additionally, the use of data in this dataset for this study will be within the context of climate which takes into considerartion long period of time. Data of specific year will not be used explicity. This project realises that this dataset is long term climate projection based on simulation process; it is not long-term forecast. They are scenarios or plausible future change in climate characteristics under changing atmospheric greenhouse gases, especially CO_2. Climate projections are important for this study as they are the input variables for an anaylysis of economic impact of climate change on farmers' net revenue in NE Thailand and for developing adaptation measures and policies climate change for the agriculture sector in NE Thailand. This project realises the uncertainty in each of the steps in the process of assessment.

4.3 Methods to Measure the Economic Impact of Climate Change on Agriculture

There are two major methods to measure the economic impact of climate change on agriculture (Mendelsohn et al., 1994; Mendelsohn and Dinar, 2003; Gbetibouo and Hassan, 2004; Seo et al., 2005; Kabubo-Mariara and Karanja, 2007; Kumar, 2009; Passel et al., 2012). These include:

i) the agronomic-economic approach or production function approach; and

ii) the spatial analogue approach or the Ricardian approach.

The former method relies upon empirical or experimental production functions to estimate environmental damage on agricultural yields by varying one or a few input variables, such as temperature, precipitation and carbon dioxide level (Mendelsohn et al., 1994). The results of this method have predicted severe yield reductions as a result of global warming (Mendelsohn et al., 1994). The latter method focuses on how climate in different places affects the net revenue or value of farmland (Mendelsohn et al., 1994; Gbetibouo and Hassan, 2004; Kabubo-Mariara and Karanja, 2007; Kumar, 2009).

A smaller number of studies have applied a third approach based on the methodology of the Food and Agriculture Organization, namely the agro-ecological zone (AEZ). This method has been particularly used in studies conducted in developing countries (Kumar, 2009; Stage, 2010). This approach assumes that when climate change leads to switches in agro-ecological zones, this will motivate farmers to adapt by shifting from the crops that they currently grown to crops that grow in the zone into which farmers are switching (Stage, 2010). This method is therefore an assessment of crop suitability to agro-ecological zones under current and changed climatic conditions in order to examine the change in production potential and the consequential economic implications (Darwin et al., 1995; Kumar, 1998).

The agronomic-economic approach has been criticized for having an inherent bias and tends to overestimate the damage from climate change (Mendelsohn et al., 1994; Kabubo-Mariara and Karanja, 2007). Although this method has the advantage of delivering reliable results in terms of the relationship between yield and climatic variables (Gbetibouo and Hassan, 2004), it fails to allow for a variety of the adaptations that farmers make in response to changing economic and environmental conditions (Mendelsohn et al., 1994; Seo et al., 2005). For example, it omits the introduction of new crops, technological change, changes in agricultural land use, or conversion to cities. As noted by Mendelsohn et al. (1994) and Kabubo-Mariara and Karanja (2007), without the inclusion of a complete range of adjustments, previous studies have overestimated damage from environmental changes.

In order to explain the general nature of the bias, Figure 4.1 shows the hypothetical values of output in four different sectors as a function of a single environmental variable; temperature.

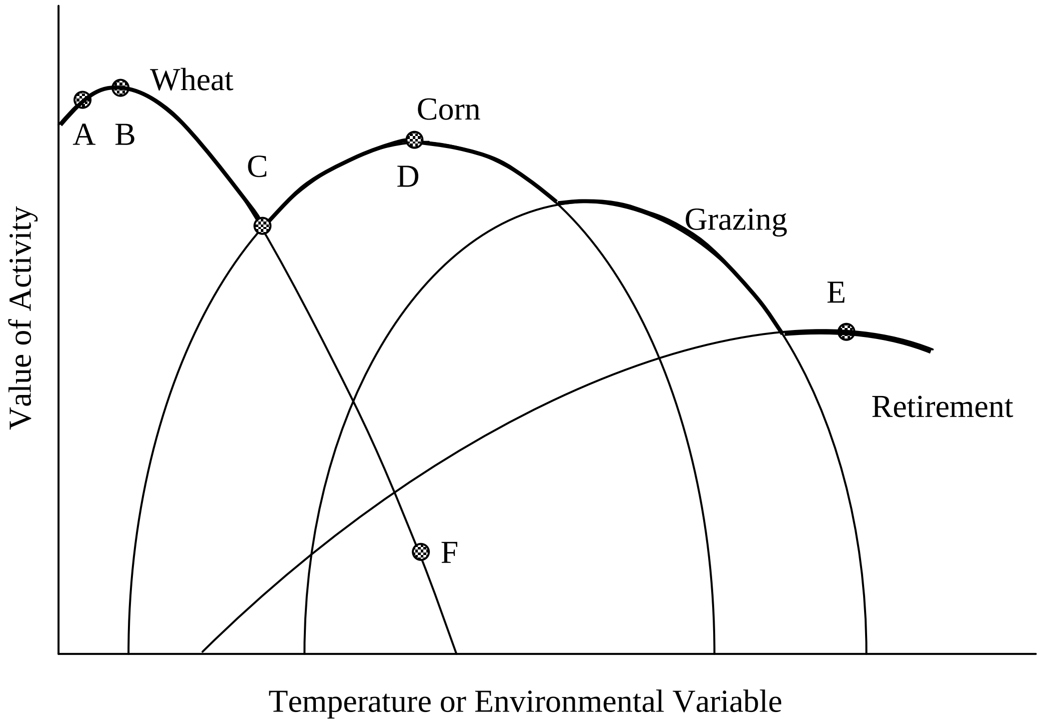


Figure 4.1 Bias in Production-Function Studies (Mendelsohn et al., 1994)

It can be assumed that the agronomic-economic or production function approach yields an accurate assessment of the economic value of the activity as a function of temperature. As demonstrated by Mendelsohn et al. (1994) a hypothetical “wheat production function”, the curve to the far left, illustrates how the value of wheat changes with temperature; increasing from cold temperatures such as point A, then peaking at point B, and finally falling as temperatures increase too high. A production-function approach would evaluate the value of wheat production for temperature changes along this curve.

Mendelsohn et al. (1994) point out that the bias in the production-function approach occurs because it fails to permit economic replacement as conditions change. As temperature increases above point C, for example, the production-function approach might estimate that the crop production has fallen to F in wheat, however, wheat is in actually no longer harvested because the adaptive and profit-maximising farmers will shift from wheat to corn since the perceived value is indeed much larger at point D of “corn production function”. At increasing temperature, the land is no longer suitable for corn but should be changed to grazing, and production-function estimates that do not allow for this substitution will again exaggerate the damage from climate change. Finally, at point E, even the perfect agricultural model will forecast that the impact of climate change is extremely severe and thus the land is inappropriate for farming or grazing. A more optimal approach might suggest that the land has been switched to a retirement village. For example, the elderly people can play golf in warm winters and dry climates. Therefore the agronomic-economic or production-function approach will over-estimate the losses from climate change because it does not, and in fact cannot, take into account the entire variety of substitutions, adaptations, and old and new activities that may convert no-longer-beneficial activities as climate changes (Mendelsohn et al., 1994).

Instead of studying yields of specific crops, the Ricardian approach examines how climate in different places affects the net revenue or value of farmland. This approach assumes perfect competition in product and input markets (Mendelsohn et al., 1994). By directly measuring farm prices or revenues, the direct impact of climate on yields of different crops is taken into account, as well as appraising the indirect substitution of different inputs, introduction of different activities, and other potential adaptations to different climates (Mendelsohn et al., 1994; Gbetibouo and Hassan, 2005; Chen et al., 2013). The Ricardian approach allows the estimation of the economic value of different activities and, therefore, verification of whether the economic impacts implied by the production-function approach are reproduced in the field (Mendelsohn et al., 1994).

As highlighted by Timmins (2006) and Stage (2010), the Ricardian approach is probably the most practical method for estimating the economic impacts of climate change. Mendelsohn et al. (2010) and Salvo et al. (2013) identify the advantages of this method in that is relatively easy to estimate the economic impacts of climate change, yields geographically precise values, and captures adaptation. Stage (2010) additionally states that climate change adaptation has to be exogenously determined in the other two methods, whilst the Ricardian method endogenously models autonomous adaptation by farmers. As noted by Mendelsohn et al. (1994), agriculture is the most appealing application of the Ricardian technique because of the significant impact of climate on agricultural productivity. Chen et al. (2013) affirm that the Ricardian analysis is an effective approach for assessing the impact of climate change on agriculture. While Salvo et al. (2013) further point out that the Ricardian approach is capable of being applied at a very small geographic scale such as a small Italian Alpine region.

Gbetibouo and Hassan (2005) argue that in the Ricardian analysis, however, adaptation costs are not considered, and it does not capture future changes affecting agriculture such as technical change since the analysis makes forecasts based on current farming practices. Additionally, this method does not take into account water supply and availability (Darwin, 1999; Gbetibouo and Hassan, 2005). It is further argued by Mendelsohn et al. (2001) that without using a sophisticated hydrological-economic model, the problem of water resource availability and access cannot be properly addressed. The model is also criticized by Cline (1996) as it treats price as constant and therefore it underestimates damage and overestimates benefits. Furthermore, Kumar (2009) suggests that it is important to account for spatial correlation in the Ricardian analysis using cross-sectional data.

4.4 Ricardian Model Specification

As noted by Kumar (2009) crop growth and the behaviour of the producers of agricultural goods would be influenced by changes in climate because such changes should be considered as a change in input structure. Kumar (2009) additionally describes a production function *F* which considers *k* purchased inputs and *l* climate inputs relate to the output. Letting P_i and Y_i be the output price and quantity of the i^{th} good, respectively, X_{ij} the quantity of the j^{th} purchased input used in the production of the i^{th} good, and q_j the price of the j^{th} purchased input, the profit-maximizing behaviour of the producer can be expressed as:

$$\text{Max } P_i Y_i - \Sigma q_j X_{ij} \tag{1}$$

which is then subject to a production function:

$$Y_i \leq F(X_{i1}, X_{i2}, \ldots, X_{ik}, E_1, E_2, \ldots, E_l) \qquad (2)$$

This specification is different from the conventional one since the environmental/climate inputs (variables *E* in the above equation) are included. Although there is no market for climate inputs, profits, input demands and output supply can be theoretically represented as functions of measured market inputs and climate variables (Kumar, 2009). However, it is difficult to obtain the functional relationship between output and changes in climate inputs based on an associated econometric analysis, hence researchers often partition the production function expressed in equation (2). To measure the supply shifts in the case of agriculture, researchers first estimate yield changes and then introduce them into economic models. While scholars commonly use such neutral technology change assumptions in the literature on climate change impacts, Kumar (2009) argued that it is not necessary to make such an assumption. Thus, equation (2) becomes:

$$Y_i \leq F_1(X_{i1}, X_{i2}, \ldots, X_{ik})^* F_2(E_1, E_2, \ldots, E_l) \qquad (3)$$

Kumar (2009) asserts that such partitioning can indicate fairly complex technical relationships among market inputs as described by econometrically related production relationships and among climate inputs as described by crop simulation models. In order to assess the economic and welfare implications, researchers often integrate the crop responses to climate parameters, estimated using crop simulation models, with either a partial or general equilibrium framework (e.g. Lobell et al., 2005; Lobell and Field, 2007; Wang et al., 2008;

Chen et al. 2010; Lobell et al. (2011); Muller et al. (2011); Auffhammer et al., 2012).

According to Kumar (2009) the Ricardian approach, on the other hand, integrates the climate response curves of numerous crops to arrive at the overall crop response curve with regard to different crops have different climatic requirements. In a clairvoyant farmer scenario, the farmer would willingly shift from one crop to another rather than suffer the losses from not shifting over. It is clear that the transition between crops would involve costs. Thus, to take into account the costs and benefits of adaptation, the relevant dependent variable should be net revenue or land values (that is, capitalized net revenues) and not yields. Therefore, the Ricardian approach estimates a variant of equation (2). Kumar (2009) explained that climate change impacts can be measured as changes in net revenue or land value as shown below.

Consider a crop with the aggregate demand Y_i and let the production function be as shown in equation (2). There will be a cost function (obtained through cost minimization) associated with Q (which expresses the set of prices of the inputs used in the production), E and Y_i, given by equation (4):

$$C_i = C_i\,(Y_i\,, Q\,, E\,) \tag{4}$$

where, C_i is the cost of production of good i. Excluding ‘land’ out of the vector of inputs X and taking its annual rent as q_l, the profit maximization equation can be written as:

$$Max \quad P_i\,Y_i\; - \;C_i\,(Y_i\,, Q\,, E\,)\; - \;q_l\,L_i \tag{5}$$

where, L_i is the amount of land used for producing Y_i. Under perfect competition for land, the rent of land can be expressed as:

$$q_l = \frac{[P_i Y_i - C_i(Y_i, Q, E)]}{L_i} \tag{6}$$

If 'i' is the best use for the land, given the environment E and factor prices Q, the observed market rent on the land will be equal to net profits from the production of good 'i'. Land value, which is the present value of the stream of revenue over time, can be defined as:

$$V_l = \int_0^{\infty} q_l \, e^{-\rho t} \, dt \tag{7}$$

The Ricardian approach investigates the relationship between land rent (equation 6) or land value (equation 7) and the independent variables, P, Q, and E.

Under the assumption that market prices will remain unchanged given environmental changes, then the welfare value of a change in the environment can be written as:

$$W(E_A - E_B) = [PY_B - \Sigma C_i(Y_i, Q, E_B)] - [PY_A - \Sigma C_i(Y_i, Q, E_A)] \tag{8}$$

Substituting equation (6) in equation (8), then:

$$W(E_A - E_B) = \Sigma(q_{lB} L_{EB} - q_{lA} L_{EA}) \tag{9}$$

where q_{lA} and q_{lB} are land prices under different environmental conditions. Alternatively, the present value of this welfare change can be given by:

$$\int_0^{\infty} W(E_A - E_B) \, e^{-\rho t} \, dt = \Sigma(V_{lB} - V_{lA}) \tag{10}$$

The definitions of the Ricardian estimate of the value of environmental changes are expressed in equations (9) and (10). It can be assumed that output prices are unchanged under changed climate conditions, the change in aggregate land values or the change in the present value of net revenues then captures exactly the value of the change in the climate. This variant of the Ricardian approach can be applied due to the non-existence of well functioning land markets in developing countries (Dinar et al., 1998; Kumar, 2009).

As suggested by Kumar (2009) the empirical strategy of the Ricardian study is to estimate a functional relationship between land value, or net revenue, and climate variables using cross-sectional data while controlling for variables that could cause variability in the dependent variable. Variability in the dependent variable caused by factors other than climate can be controlled through:

(a) soil characteristics (soil quality could differ significantly across the cross-section could lead to variability in the farm-level net revenue);

(b) the level of technology penetration (wide spread across the cross-sectional units in terms of mechanisation, and penetration of growing innovations leading to variability in the dependent variable);

(c) the extent of development (different opportunity cost of land and market access and alternative livelihood opportunities across the cross-sectional units could be contributable to the variability in the farm-level net revenue).

Thus, the Ricardian model can be specified as follows:

$$NR = f(T_j, T^2_j, R_j, R^2_j, T_jR_j, SOIL, BULLOCKS, TRACTORS, CULTIVATORS, POPDEN, LITPOP, IRR) \quad (11)$$

where, NR represents farm-level net revenue per hectare and T and R represent temperature and rainfall respectively. According to Meldelsohn and Dinar (2003); Gbetibouo and Hassan (2004) and Kumar (2009), it is noteworthy that a quadratic functional specification along with climate interaction terms should be adopted in each study. As noted by Kumar (2009), the climate coefficients have not significantly changed when they include the prices of major cereal crops in the model specification. However, no evidence exists from previous studies about the influence of input prices. It is therefore assumed their cross-sectional variation is not significant (Kumar, 2009).

Other explanatory variables that may be included are soil; farm households own bullocks, tractors and cultivators; population density; literate population and irrigated land where soil represents soil quality, farm households own bullocks, tractors and cultivators represent the extent of mechanization, whereas population density, literate population and irrigated land represent the extent of development.

To examine how changing climate variables including temperature and precipitation are impacting the farmers' income in NE Thailand, the Ricardian approach is selected. As there is a variety of crops cultivated in the region, such as rice, cassava, sugarcane, maize, para rubber, fruits and vegetables. The Ricardian approach may be successfully applied to the case of NE Thailand as the geographical distribution of the crops under study seem to be highly correlated with variation in climate patterns across the region. In addition, the Ricardian analysis has been applied at very small geographic scales (Salvo et al, 2013). It is therefore practical to employ the Ricardian model to NE Thailand. As highlighted by Timmins (2006), the Ricardian model can use readily available data on land values or net revenues from agricultural production, therefore eliminating the need for costly field studies or the collection of expensive panel data over long period of time. These agricultural data are readily accessible in Thailand, which enables this study to carry out the Ricardian analysis for NE Thailand. Moreover, the Ricardian method can provide a useful starting point for policy interventions. According to Stage (2010), a Ricardian study can help identify the production patterns that farmers are likely to switch to, given the anticipated changes in climate; policy makers and analysts can use these projections to identify policy measures that can make it easier for farmers to switch to these new production patterns.

4.5 Adaptation and Managing Risks in Agriculture

Global agriculture is threatened by a changing climate, including severe weather events and the ongoing consequences of drought, heavy rainfall, invasive weeds, and crop and livestock diseases (Sauchyn and Kulshreshtha 2008; Rosenzweig and Tubiello 2007; Reidsma et al. 2010; Anwar et al., 2013). Agriculture is identified within the UNFCCC Convention as particularly vulnerable to climate change (Wreford et al., 2010). International response should take place under the Convention *"within a time-frame sufficient to allow ecosystems to adapt* *naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"* (UNFCCC, undated e).

Adaptation of food systems is crucial for dealing with the unavoidable impacts of climate through the adjustment of practices, processes and capital in response to the actuality or threat of climate change (IPCC, 2014). Adaptation can also enhance opportunities from climate change (Tubiello et al., 2008; Wreford et al., 2010). New markets for innovative insurance products and other risk-based financial services, for example, could emerge as a result of rising damage caused by climate change (Botzen et al., 2009; 2010) The Stern Review indicated that there could be significant new opportunities across a wide range of industries and services; markets for low-carbon energy products are likely to be worth at least $500bn per year by 2050, and perhaps much more (Stern, 2007).

4.5.1 Types of adaptation

According to IPCC (2014), adaptation is the process of adjustment to actual or expected climate and its effects. Adaptation in agriculture ranges from small adjustments made to current activities through to transformative adaptations across whole systems. The two main types of adaptation are autonomous and planned adaptation (FAO, 2007; Stokes and Howden, 2010).

Autonomous adaptations are incremental adjustments in the farming system through the continuing utilisation of indigenous insight and technology in response to the changes in climate experienced in order to minimise risk and vulnerability (IPCC, 2014). Autonomous adaptations are reactive in nature. There is substantial commonality in adaptation actions within different agricultural systems, for example, changing varieties and planting times are incremental adaptations found in studies of many different cropping systems (e.g. Monzon et. al., 2007; Meza et al., 2008; Orlandini et al., 2009; Tingem and Rivington, 2009; Passioura and Angus, 2010; Walter et al., 2010 and Cho et al., 2012). However, incremental adaptations are expected to have increasing limitations as the climate further changes, raising the need for more systemic or transformational changes (IPCC, 2014).

Planned adaptations are proactive and can either diversify the broader system or transform it (Howden et al., 2010). In regions where temperature has been a past limitation, such as Russia, Canada and northern Norway, warmer conditions may allow range expansion of cropping activities polewards (e.g. studies for Russia: Alcamo et al., 2007; Bindi and Olesen, 2011; Dronin and Kirilenko, 2011; Tchebakova et al., 2011; for Canada: Kulshreshtha, 2011; and for northern Norway: Kvalvik et al., 2011). This is an example of transformational change. However, latitudinal expansion of cold-climate cropping zones polewards may be vastly offset by reductions in mid-latitude cropping areas and yields due to rainfall reduction, water shortages and temperature increase (IPCC, 2014).

4.5.2 Climate Risk Management Approach

The International Standards Organization (2009) ISO:31000 defines risk as *the effect of uncertainty on objectives*. In the context of climate change, risk can be *the potential for consequences where something of human value (including* *humans themselves) is at stake and where the outcome is uncertain* (Rosa, 2003). Making decision in climate change context involves long time scales that have led uncertainties associated with many risks (Kandlikar et al., 2005; Ogden and Innes, 2009; Lempert and McKay, 2011), e.g. climate change, socio-economic change and potential changes in norms and values within and across generations (IPCC, 2014).

In climate change decision-making, it is crucial to use methods that are best for assessing adaptation. No single method suits all contexts, but the overall approach used and recommended by the IPCC (2014) is iterative risk management. Iterative risk management is a decision-support framework for climate impact, adaptation and vulnerability assessment, which involves an ongoing process of assessment, action, reassessment, and response (Kambhu et al., 2007; IRGC, 2010). Iterative risk management offers formalised methods for addressing uncertainty, involving stakeholder participation, identifying potential policy responses, and evaluation of those responses (Carter et al., 2007; IPCC, 2007; Yohe et al., 2007). Figure 4.2 depicts the assessment process in iterative risk management. The process is reflexive and allows for changes in knowledge and a revision of criteria and objectives as well as an identification of risks or circumstances and responses.

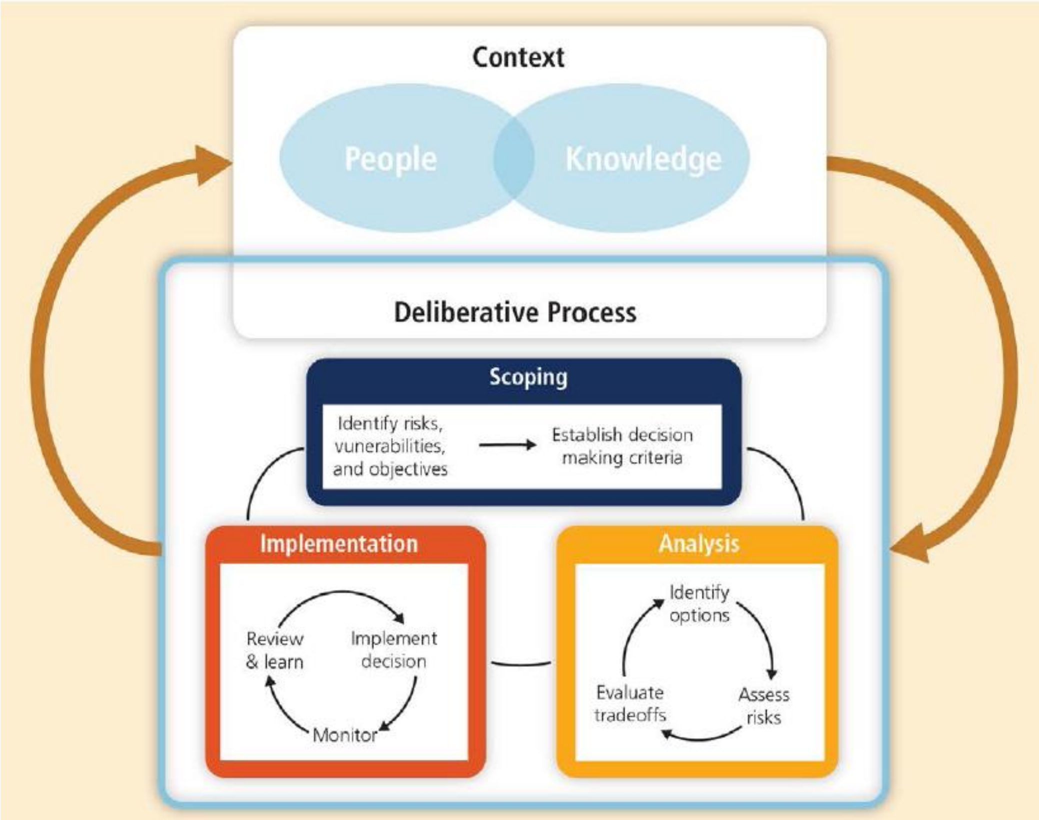


Figure 4.2 Iterative Risk Management (IPCC, 2014)

According to Willow and Connell (2003), an iterative process comprises three separate aspects including circular, iterative and tiered. First, the circular allows the performance of a review and reconsideration of decisions taken through time, with regarding to new information on climate change and its impacts. Existing climate change policies and adaptation strategies can be identified as input or constraints to the process. Second, the iterative process allows a refinement of the problem, decision-making criteria, risk assessment and options prior an implementation of any decision. Third, the tiered approach allows the policymakers to carry out screening, evaluation and prioritisation of climate risks and options for decision, which promote adaptation to climate change (DETR, 2000).

4.5.3 Risk in agriculture

Reductions in mean crop yield because of climate change are the key risks for food security and climatic drivers of these impacts include warming trend, extreme temperature, drying trend, extreme precipitation, carbon dioxide concentration and ocean acidification (IPCC, 2014). Over the past half century, many studies of cropping system have employed both mechanistic and statistical approaches to estimate impacts of observed climate changes on crop yields and have found that climate trends have negatively affected wheat and maize production for many regions, but effects on rice and soybean yields have been small in major production regions and globally (e.g. studies for wheat: Lobell et al., 2005; Wang et al., 2008; Ludwig et al., 2009; You et al., 2009; Brisson et al., 2010; Licker et al., 2013; for rice: Auffhammer et al., 2012; Welch et al., 2010; and for combinations of crops: Pathak et al.,2003; Tao et al., 2006; Lobell and Field, 2007; Kucharik and Serbin, 2008; Tao et al., 2008; Schlenker and Roberts, 2009; Chen et al., 2010; Lobell et al., 2011; Tao et al., 2012).

Extreme events clearly have had significant impacts on cropping systems over the past decade (IPCC, 2014). The economies of many developing countries rely heavily on agriculture which are dominated by small-scale and subsistence farming, and livelihoods in this sector are especially exposed to weather extremes (Easterling and Apps, 2005; Easterling et al., 2007). Droughts in Africa, especially since the end of the 1960s, have impacted agriculture resulting in substantial famine (IPCC, 2012). Subsistence farmers can be severely impacted by climate and weather events, for example, nearly all of households produce maize in Kenya only 36% sell it but the great majority eat all they produce (FAO, 2009a). Both such famers and their governments have limited capacity for recovery (Easterling and Apps, 2005).

Evidence that the current warming trends around the world have already impacted agriculture is reported by Lobell et al. (2011); the study states that global crop production has been negatively affected by climate trends since the 1980s, with maize and wheat production declining by 3.8% and 5.5%, respectively, compared to a model simulation without climate trends. The evaluations of projected temperature effects on crops in the United States and Africa by Schlenker and Roberts (2009) and Muller et al. (2011), respectively, conclude that climate change would have negative impacts on crop yields; these effects are based on temperature trends and an expected increase in the probability of extremes during the growing season, however, there is also the potential occurrence of extreme events after the crop is grown, which could affect harvest and grain quality.

Fallon and Betts (2010) show that robust management practices are required to offset negative impacts of increasing risks from flooding and drought on agricultural production. Their analysis for Europe indicated a probable increase in crop productivity in northern regions but a decrease in the southern regions, leading to a greater disparity in production.

The effects of climate trend on agriculture can be attributed to the anthropogenic influence on the climate system, for instance, Min et al. (2011) discuss that changes in rainfall extremes over the period 1951-99 are attributable to human-induced activity and Rosenzweig et al. (2002) states that flooding and excess precipitation events in the US and worldwide have caused great damage to cropping systems. In addition, Zwiers et al. (2011) and IPCC (2012) attribute reductions in frost since 1961 to greenhouse gas emissions in nearly every region of the world and frost damage is concerned as another substantial constraint on crop growth in many crops.

Over the past decade, international food prices spiked twice in 2008 and 2011. These spikes have ignited concerns about food price crisis and have prevented millions of people from escaping poverty because the poor spend large shares of their incomes on food and because many poor farmers are net buyers of food (World Bank, 2012c). In recent years, prices may have become more sensitive to weather-related supply shortfalls and, at the same time, food prices have been increasingly associated with the price of crude oil (World Bank, 2012c; IPCC, 2014). However, the role of weather in food price increases remains unclear since prices reflect the overall balance of supply and demand, and the accessibility of food for consumers integrated with regional to global markets (IPCC, 2014).

Projections for food and agriculture over the 21st century indicate substantial challenges irrespective of climate change (World Bank, 2012c). As early as 2050, the world’s population is projected to reach about 9 billion people (DESA, 2013) and demand for food is expected to increase accordingly. FAO (2009b) suggested that in order to feed this larger, more urban and richer population, food production (net of food used for biofuels) must increase by 70%. In other estimations for the same period, Tilman et al. (2011) projected a 100-110% increase of global crop demand from 2005 to 2050, and Thornton et al. (2011) suggested that global cereal and livestock production may need to increase by 60-100 % to 2050, depending on the warming scenario.

In general, decreases in mean yields are considered negative outcomes for food security; associated with the expected increases in global crop demand, agricultural productivity improvements are required in order to keep pace with demand (IPCC, 2014). As noted by FAO (2007), the developing world already contends with chronic food problems and climate change has worsened the situations of vulnerable populations. Those least able to cope will likely bear additional negative impacts (World Resources Institute (WRI), 2005). As asserted by IPCC (2013 and 2014) the rigorous adverse impacts of climate on food security and production, the commitment to future climate change from past greenhouse gas emissions and the very high likelihood of additional and likely greater climate changes from future greenhouse gas emissions means that some level of adaptation of food systems to climate change will be necessary. In addition, effective monitoring and prediction, and building resilience into food systems, are likely to be important tools in avoiding the negative impacts resulting from these interactions (Misselhorn et al., 2010).

4.5.4 Indigenous knowledge

Indigenous knowledge plays a key role in climate risk management (IPCC, 2014). Indigenous knowledge has been defined as *institutionalized local knowledge that has been built upon and passed on from one generation to the* *other by word of mouth* (Osunade 1994; Warren 1992). Indigenous knowledge is the basis for local-level decision-making in many rural communities (Nyong et al, 2007). Local knowledge can be utilised to complement scientific climate data, to provide insights about and for climate change adaptation (Krupnik and Jolly, 2002). Berkes and Folke (2000) claimed that traditional ecological knowledge is a potential source of resilience.

For example, the Ovambo farmers in North Central Namibia have developed 'indigenous land units' or a local land-use classification system, which permits them to build enduring resilience to high levels of climate variability and associated impacts (Newsham and Thomas, 2011). Farmers in the African Sahel make decisions on cropping patterns based on local predictions of climate (Nyong et al, 2007). In addition, the zaï technique, a traditional integrated soil and water management practice, is implemented in the West African Sahel region to combat land degradation (Fatondji et al, 2009).

To identify which sub-regional areas/units (provinces, districts or sub-districts, depending on the availability of the data) of NE Thailand are the most risk to climate change and to examine and develop adaptation measures and policies climate change for the agriculture sector in NE Thailand, this thesis uses a geographic CCR 'hotspot' analysis to explore where future climate stressors may have the greatest impact within NE Thailand. This technique can provide policymakers adequate information on risks and vulnerabilities of the agriculture sector in NE Thailand. These studies aim to reduce risks and build adaptive capacity of the farmers in the region.

4.6 Input Data

4.6.1 Data Collection Method

Data collection was designed to fulfil the information requirements to answer the research questions. This research employed secondary analysis and official statistics in order to review and scope of existing climate change studies from international, national and regional perspectives, with a particular focus on NE Thailand.

Secondary analysis is the analysis of data by researchers who will probably not have been involved in the collection of those data for purposes that in all likelihood were not considered by those responsible for the data collection (Bryman, 2012). There are two main types of data employed in this research; the secondary analysis of data collected or developed by other researchers and the secondary analysis of official statistics collected by government departments in the course of their work or specifically for statistical purposes.

Secondary analysis offers numerous benefits when one is carrying out a research project. The data have already been collected therefore considerable time and expense may be saved. Numerous data sets are available from Data Archives, which are housed at most academic libraries or provided via the Internet. The data sets are generally of extremely high quality because those have been gathered by researchers or organisations that have developed structures and control procedures to check on the quality of the emerging data (Bryman, 2012). Precisely because the data are complied over many years, it is possible to analyse the data over time which offers the opportunity for longitudinal research and perhaps to relate these to wider social changes. There is the prospect as well of cross-cultural analysis, since the official statistics from different nations or regions can be compared for a specific area of activity.

However, there are some limitations of secondary analysis. According to Bryman (2012), a period of familiarisation is necessary since the data were collected by others. For example, researchers have to get to grips with the range of variables, the way in which the variables have been coded, and various aspects of the organisation of the data. The period of familiarisation can be quite substantial with large complex data sets. Despite this, secondary analysis offers the opportunity for researchers to examine data of far higher quality than they could collect themselves. However, it may not meet all of a prospective secondary analysis' needs, since data may not have been collected on an aspect of a topic that would have been of considerable interest (Bryman, 2012). Issues of reliability and validity of official statistics should be in considerations because definitions and policies regarding the phenomena to be counted vary over time (Bryman, 2012).

A comprehensive province-level dataset for the period 1984 to 2010 is used for the purpose of the analysis in this research. Provinces are the lowest administrative unit at which reliable agricultural data are available in Thailand. The year 1984 was the earliest year in which agricultural data for Thailand were published. NE Thailand comprises 20 provinces. Three of these provinces were established after 1984, including Nong Bua Lam Phu, Amnat Chareon and

Bueng Kan provinces. Bueng Kan province was established in 2011, hence there are no climate, agricultural and socio-economic data available for an analysis. The data for Nong Bua Lam Phu and Amnat Chareon provinces are available from 1994, thus the time-series exclude ten years of the data. In order to retain the long period of the dataset, which enables the analysis to explicitly detect the impact of climate variables on the farmer net revenue, the data of these two provinces were integrated back into their original provinces: Nong Bua Lam Phu province data were integrated into Udon Thani province data and Amnat Chareon province data were integrated into Ubon Ratchathani province, respectively. Therefore, the province-level dataset of this study covers only 17 provinces including Khon Kaen, Udon Thani, Loei, Nong Khai, Mukdahan, Nakhon Panom, Sakon Nakhon, Kalasin, Nakhon Ratchasima, Chaiyaphum, Yasothon, Ubon Ratchathani, Roi Et, Buri Ram, Surin, Maha Sarakham and Si Sa Ket. Figure 4.3 shows map of provinces in NE Thailand.

Figure 4.3 Provinces in Northeast Thailand

Source: Department of Provincial Administration, Ministry of Interior

Agricultural data at the provincial level were assembled along with the relevant climatic, demographic and macro-economic data in the dataset. The related official statistics include agricultural, climate and socio-economic data and are outlined in the following section.

4.6.2 Agricultural data

Agricultural data adopted in this research are collected by the Office of Agricultural Economic (OAE) and Land Development Department (LDD), Ministry of Agriculture and Cooperatives (MoAC), Kingdom of Thailand. The related agricultural statistics include:

- Total cropped area, production and price under three major crops including rice, cassava, and sugarcane and other fourteen economic crops such as maize, para rubber, soybeans, goundnuts, mungbeans, shallot, garlic, potato, kenaf, cotton, longans, pineapples, oranges, and durians.

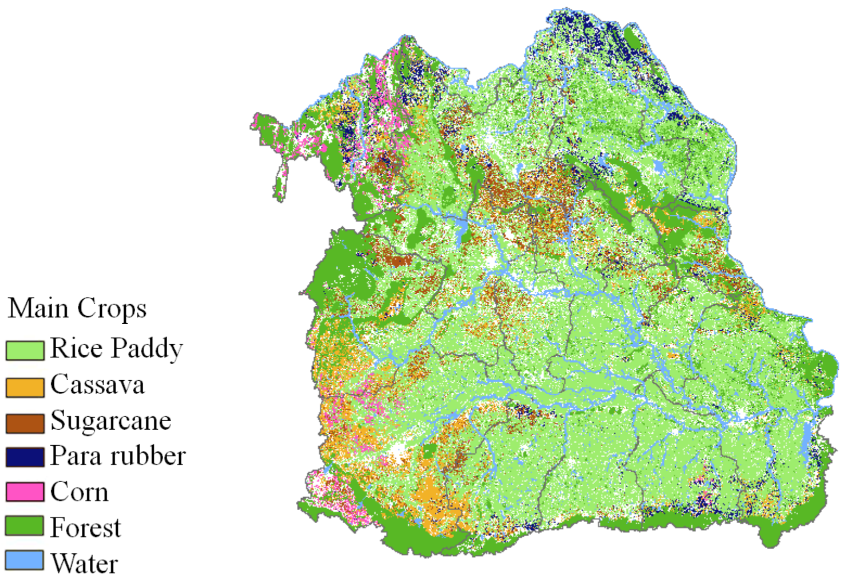


Figure 4.4 Main Crops in Northeast Thailand

Source: Author’s compilations based upon land-use dataset from LDD

In this study the farm level net revenue per hectare (NR) is employed as the dependent variable because annual NR is directly and easily calculable from the agricultural dataset, and the land values in some areas are boosted by the land scarcity and the competition with other land uses. For the purposes of analysis, farm level net revenue per hectare is defined as follows:

$$\text{Net Revenue per ha} = \frac{(\text{Gross Revenue}) - (\text{Costs})}{\text{Total Area}} \quad (12)$$

where, gross revenue is calculated over the seventeen crops mentioned above and where the total area is the cropped area under the seventeen crops, the costs are the total yearly costs incurred towards the use of inputs for all the crops such as seeds, fertilizer, fuel and labour. It is noteworthy that this study will not include costs attributable to irrigation, and tractors in the net revenue calculations because appropriate prices are difficult to identify. However, these variables are adopted as control variables in the model, as specified in equation (11).

- Cost of agricultural productions which is available at region level. These data therefore are needed to predict the cost of production at the provincial level using simple regression analysis based on the relationship of average gross revenue ($/ha) on cost of production ($/ha) for each crops in this study.

- Soil quality data are captured through the fraction of area under five soil orders consist of alfisols, inceptisols, oxisols, ultisols and vertisols across the region as proximity of soil quality. The areas are measured from the soil map for Thailand developed by Land Development Department (LDD). The soil dataset reports 62 soil groups in Thailand. This study adopted the eleventh edition of the *Keys to Soil Taxonomy* developed by United States Department of Agriculture, Natural Resources Conservation Service (USDA, 2010) to classify 62 soil groups into soil orders and found that there are five soil orders (out of twelve orders) spread throughout NE Thailand (Figure 4.5).

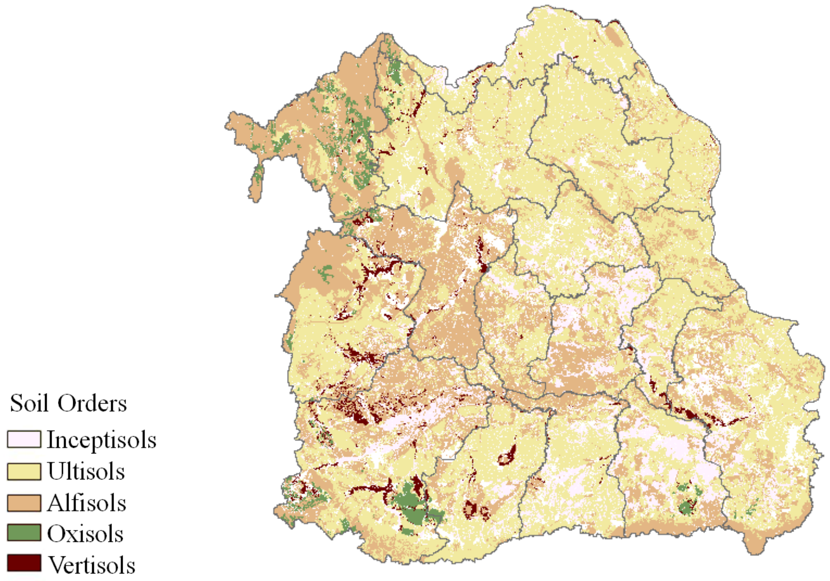


Figure 4.5 Soil Orders in the Northeast

Source: Author's compilations based upon soil dataset from LDD

4.6.3 Climate Data

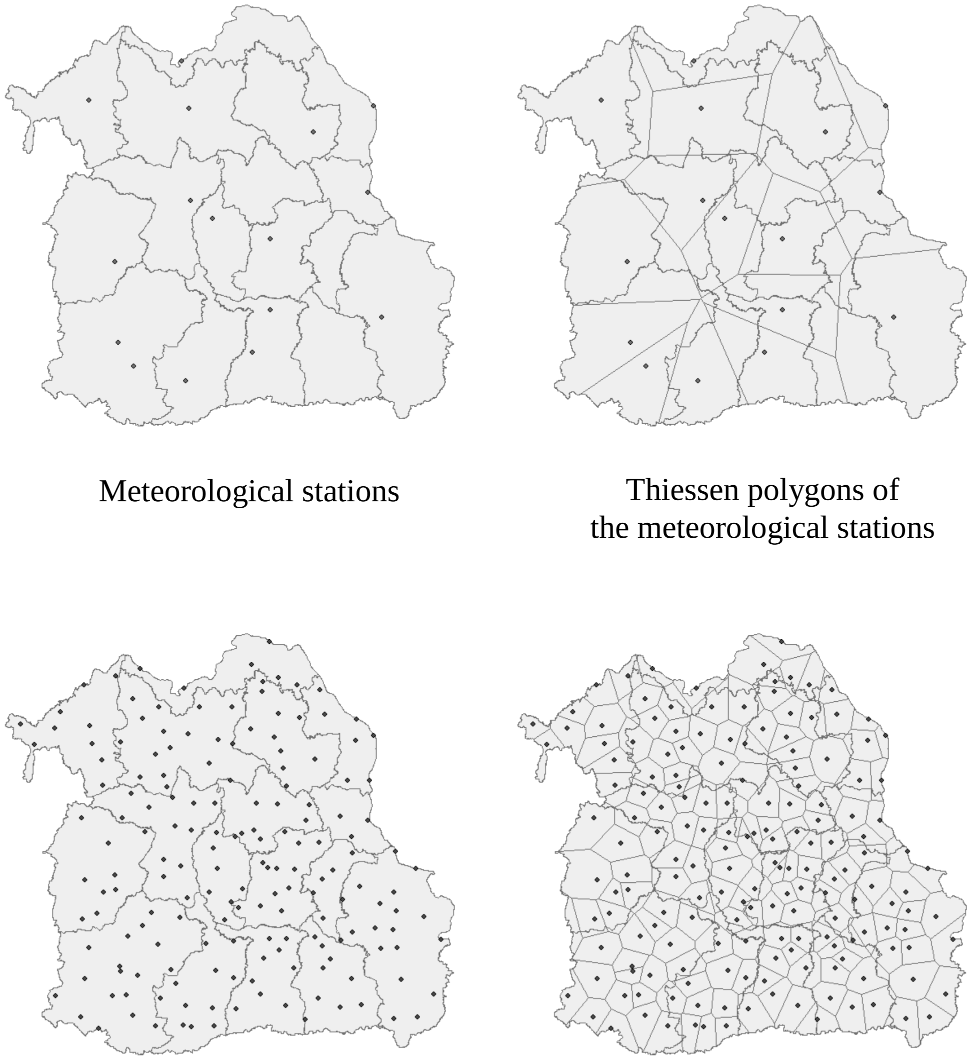
Observed climate data

Observed climate data for this analysis are collected by meteorological stations and hydro-meteorological stations in the region governed by the Thai Meteorological Department (TMD), Ministry of Information and Communication Technology. This study uses climate data corresponding to 16 meteorological stations and 173 hydro-meteorological stations spread across NE Thailand for the purpose of developing provincial level climate. The data on climate – at the meteorological stations or hydro-meteorological stations and hence at the provinces – correspond to the average observed weather over the period 1984-2010 as the database of the TMD. The project represent all the climate variables through three months; April, August and December, corresponding to the three seasons; summer, rainy and winter, respectively. April is the hottest month of the year, August is the wettest month, and December is the coolest month. The average maximum temperature (°C) and total seasonal precipitation (mm/month) for each of these three seasons over the period 1984-2010 for each of the 17 provinces represent the climate variables used in the Ricardian model.

In order to ensure that the farmers in each year respond to the climate that they experiences, Kumar (2009) suggests that annual climate for each province should measured by using the rolling averages of 30 year weather data. That is, for the year 1984 the average weather over the period 1955 to 1984 would serve as climate, whereas for the year 1990, the average weather over the period 1961 to 1990 would serve as climate. However, the annual weather data for this study are available only from 1980 to 2010. Hence, the study takes the assumption that the climate has not changed significantly over the study period and that the average weather over the 30 year period is highly correlated. Kumar (2009) points out that in his analysis of the climate sensitivity of Indian agriculture between the period 1951 to 1980 reported almost similar results as a study on climate change impacts on Indian agriculture by Sanghi and Mendelsohn (2008) using climate data corresponding to the period 1930 to 1960. This is seen as justification for the above claim that the climate has remained stable over the study period (Kumar, 2009).

In order to estimate the monthly temperatures and precipitation for each province in NE Thailand, the study applied proximity analysis in ArcGIS to create Thiessen polygons from input point features (ESRI, 2010a). As the temperatures and precipitation are measured at point or location of 16 meteorological stations and 173 hydro-meteorological stations throughout the region, these stations are hence the input point features used to create Thiessen polygons. Figure 4.6 depicts the input points and Thiessen Polygons of meteorological stations and hydro-meteorological stations in Northeast Thailand.

By applying this technique, the polygon features that divide NE Thailand space and allocate it to the nearest point feature are generated. Thiessen polygons are sometimes used instead of interpolation to generalise a set of sample measurements to the areas closet to them (ESRI, 2010a). Thiessen polygons can be thought of as modelling the catchment area for the points, as the area inside any given polygon is closer to that polygon's point than any other. In this study, Thiessen polygons are exploited to generalize temperature and precipitation measurements to the areas around the stations.



Meteorological stations

Thiessen polygons of the meteorological stations

Hydro-meteorological

Thiessen polygons of the hydro-meteorological stations

Figure 4.6 Thiessen Polygons of meteorological stations and hydro-meteorological stations in Northeast Thailand

Source: Author's compilations based upon data from TMD

To estimate the area-averaged temperature or precipitation for each province, the formula is defined as follows:

$$\textit{Area-averaged climate of each province} = \frac{\Sigma\ (\textit{Climate Value x Thiessen Area})}{\Sigma\ (\textit{Thiessen Area})} \quad (13)$$

Climate change scenarios for NE Thailand

Climate change scenarios for NE Thailand under the IPCC SRES A2 and B2 GHG scenarios over the period 1980-2099 have been retrieved from the SEA START RC climate change data distribution system (website: http://gis.gms-eoc.org/ClimateChange/). The ArcGIS Spatial Analyst extension provides tools for spatial data analysis. To create a surface grid from points of NE Thailand climate change scenarios an interpolation tool was employed. Interpolation is a procedure used to predict the values of cells at locations that lack sampled points using the principle of spatial autocorrelation or spatial dependence to measure degree of relationship or dependence between near and distant objects (Child, 2004).

There are two categories of interpolation methods: deterministic and geostatistical. The deterministic interpolation methods create surfaces based on surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface while the geostatistical interpolation methods are based on statistical model and are used for more advanced prediction surface modelling (Child, 2004; ESRI, 2010b). The key interpolation methods such as Inverse Distance Weight (IDW), Spline and Kriging use different approaches for determining the output cells. IDW and Spline are two deterministic techniques that create surfaces from samples based on the extent of similarity or degree of smoothing. A spline surface passes exactly through each sample points but an IDW surface will pass through none of the points. Kriging is a geostatistical technique that uses powerful statistical methods for predicting values derived from the measure of relationship in samples and employs sophisticated weighted average techniques.

This study applied spline interpolation technique to create area-averaged surfaces air temperature and precipitation of the region for four 30-year time slices averaged over 1990s, 2020s, 2050s and 2080s using the average of climate data year 1980-2009, 2010-2039, 2040-2069 and 2070-2099, respectively. Values are estimated using a mathematical function that minimizes overall surface curvature. This results in a smooth surface that passes exactly through the input points. According to Childs (2004), spline is the best method for representing the smoothly varying surfaces of phenomena such as temperature. In addition, spline generally produces better surfaces than IDW with the relatively small number of sample values (NREM, 2013).

4.6.4 Socio-economic Data

The levels of technology penetration in terms of mechanisation are captured through the number of holdings of bullocks, walking tractors (two-wheel tractors) and cultivators (four-wheel tractors) per hectare. These data are collected by Community Development Department, Ministry of Interior, Kingdom of Thailand.

The extent of development is captured through population density, the percentage of literate population and the fraction of area under irrigation. Population density data are published in the website of the National Statistical Office of Thailand, Ministry of Information and Communication Technology. The percentage of literate population data are collected by Community Development Department, Ministry of Interior. The fraction of area under irrigation data are measured from the irrigation map developed by Royal Irrigation Department, Ministry of Agriculture and Cooperatives.

Currency exchange rates between Thai Baht and US Dollar during 1984-2010 are collected for the purpose to calculate the dependent variable; farm-level net revenue per hectare which converted from Thai Baht to $. These data can be retrieved from the website of the Bank of Thailand (www.bot.or.th).

4.6.5 The Problem of Missing Data

One major problem in this study is the missing data of four variables; literacy, bullocks, tractors and cultivators. For the percentage of literate population, the survey started in 2002 and it has been collected every year since then. While data on households per hectare own bullocks, small tractors and cultivators have been collected since 1990, these surveys are administered every two years. There inevitably represent missing data included in the dataset.

To deal with the missing data, the project applied SPSS's data imputation application to impute 20 datasets for incomplete cases of four variables including literacy, bullocks, tractors and cultivators. For literacy, the average of 20 imputed data was filled into the original dataset for each year. For bullocks, tractors and cultivators, there are trends in each dataset. The bullock variable has a descending trend while tractors and cultivators variables have ascending trends. Therefore, the imputed values of bullocks were descending sorted while tractors and cultivators were ascending sorted, and then duplicate values were removed from each imputed dataset. The missing cases of these three variables were filled with the imputed values which fitted their trends. Finally, the new dataset for estimating the climate response function were completely filled. The new dataset is then the balance panel data and is allowed to compile into the Ricardian model of this study.

Chapter 5

Climate Change Projections for Northeast Thailand

5.1 Introduction

In 2007, a climate change research program was initiated to develop climate change scenarios in Thailand to use in a subsequent impact assessment. The program is funded by the Thailand Research Fund (TRF) (SEA START RC, 2010). The climate change scenarios for Thailand and surrounding countries have been developed by SEA START RC under the climate change research program (Chinavanno et al., 2009). These climate change scenarios are principal elements for many other subsequent assessments in the Greater Mekong Sub-region (GMS) (Krittasudthacheewa et al., 2012), including this study. Climate change projections are essential for the further assessment of impacts on agriculture and to formulate climate change adaptation planning for NE Thailand.

Key climate change characteristics in NE Thailand can be used as a guideline for policymakers. A summary of future change in terms of maximum temperature, minimum temperature and precipitation shows the spatial pattern of distribution of temperature and precipitation over the region during the early, middle and the end of the 21st century. This chapter focuses on long-term climate projections for NE Thailand. The remainder of this chapter is structured in four sections: section 5.2 presents the estimates of observed climate data in NE Thailand, followed by section 5.3 which provides details about the interpolation method used in this study to create climate change maps for the region. Section 5.4 reports the results of climate change projection for NE Thailand and the last section discusses the results of this study with those of previous studies.

5.2 Observed Climate Data of the Northeast

By applying the Thiessen Polygon methodology to generalise temperature and precipitation measurements to the areas around the meteorological and hydro-meteorological stations, the monthly area-averaged climate data can be estimated for each province in NE Thailand. Table 5.1 shows observed monthly maximum temperature, minimum temperature and precipitation of NE Thailand averaged over 1980-2009, and Figure 5.1 demonstrates monthly area-averaged climates of NE Thailand over the same period. Notably, April is the hottest month, December is the coolest month and August is the wettest month of the year in the region.

Maha Sarakham, Ubon Ratchathani and Khon Kaen provinces are recorded as the hottest provinces in the region, with the average maximum temperature of 36.56°C, 36.41°C and 36.38°C, respectively (see the Appendix Table A39). Loei, Nong Bua Lam Phu and Sakon Nakhon provinces are recorded as the coolest provinces, with the average minimum temperature of 14.85°C, 15.79°C and 16.11°C, respectively (see the Appendix Table A40). By using the average precipitation in August as an indicator, Nakhon Phanom, Nong Khai and Sakon Nakhon provinces are the wettest provinces, with the average precipitation of 458.88, 447.90 and 356.00 mm/month, respectively, while Nakhon Ratchasima, Chaiyaphum and Loei are the driest provinces in NE Thailand, with average precipitation of 146.96, 171.64 and 185.56 mm/month, respectively (see the Appendix Table A38).

Table 5.1 Observed Monthly Area-Averaged Climates of NE Thailand (1980-2009), calculated based upon data from TMD

Region	Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Precipitation (mm)
Northeast	Jan	30.66	17.14	4.01
	Feb	33.10	19.68	14.88
	Mar	35.19	22.37	38.41
	Apr	36.10	24.44	79.47
	May	34.38	24.68	182.68
	Jun	33.25	24.80	198.33
	Jul	32.68	24.54	202.94
	Aug	32.16	24.33	255.72
	Sep	31.79	23.92	247.27
	Oct	31.41	22.80	110.48
	Nov	30.70	20.12	19.19
	Dec	29.55	17.09	2.81

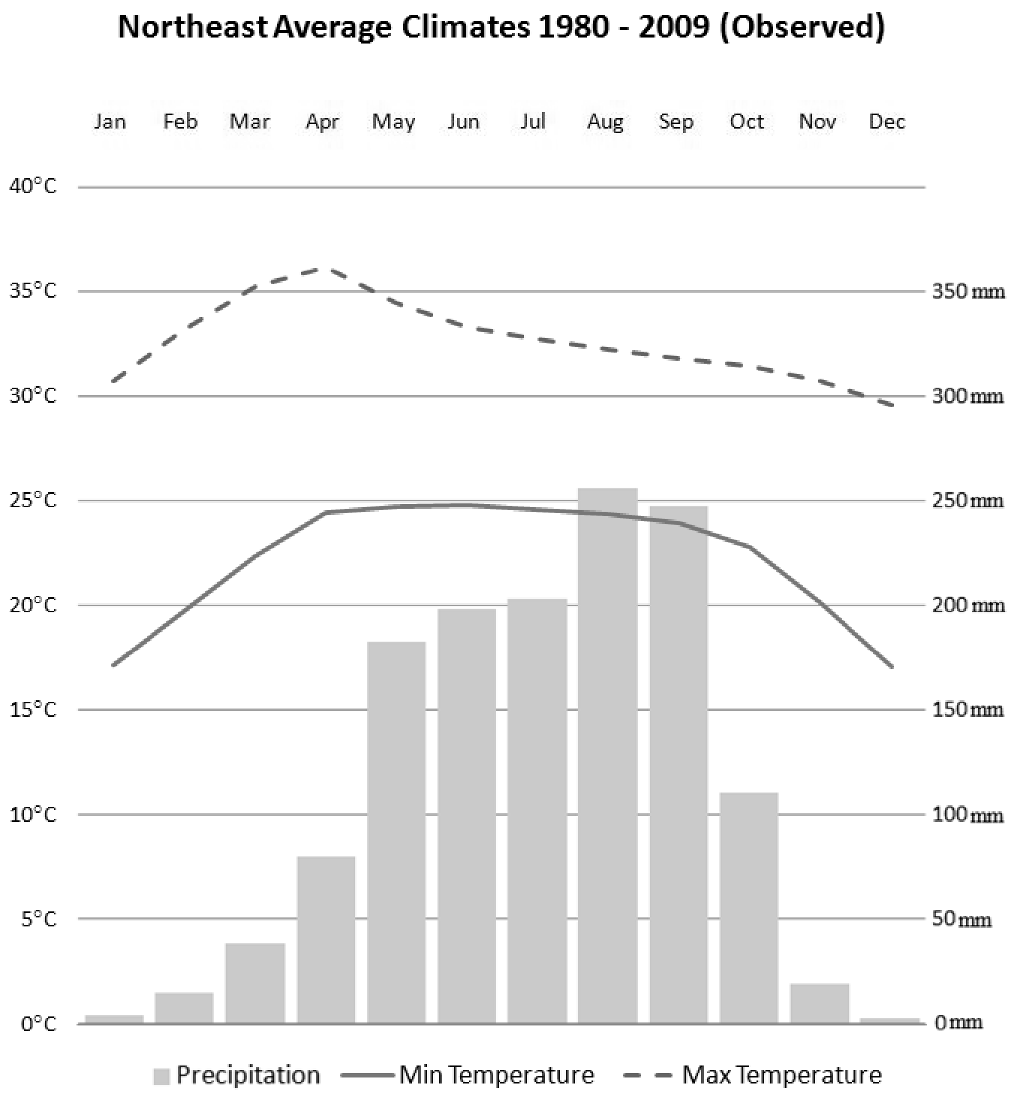


Figure 5.1 Monthly Area-Average maximum temperature, minimum temperature and precipitation for NE Thailand in the baseline period determined from Theissen Polygon analysis of TMD data

5.3 NE Thailand Climate Change Scenario Map Establishments

Climate change projections for NE Thailand under the IPCC SRES A2 and B2 GHG scenarios over the period 1980-2099 were retrieved to create maps of surface air temperatures and precipitations of the region for four 30-year time slices averaged over 1990s, 2020s, 2050s and 2080s by using spline interpolation methods (Figure 5.2 and Figure 5.3). These datasets are long-term climate projections based on simulation process and are derived from daily data. There are, however, only 360 days in one year from PRECIS model. The data grid size is 20 x 20 km and the reference latitude and longitude is located in the centre of the grid. The NE Thailand domain coverage is Lat. 14.0° - 18.6°N and Long. 100.6° - 105.8°E (Figure 5.2). The climate data required for this study include maximum temperatures, minimum temperatures and precipitation. The period 1980-2009 is defined as the baseline period because it covers the time range of a comprehensive province-level dataset used in this research (1984-2010). During the baseline period, the SEA START RC climate change data distribution system provides the same climate data between A2 and B2 GHG scenarios.

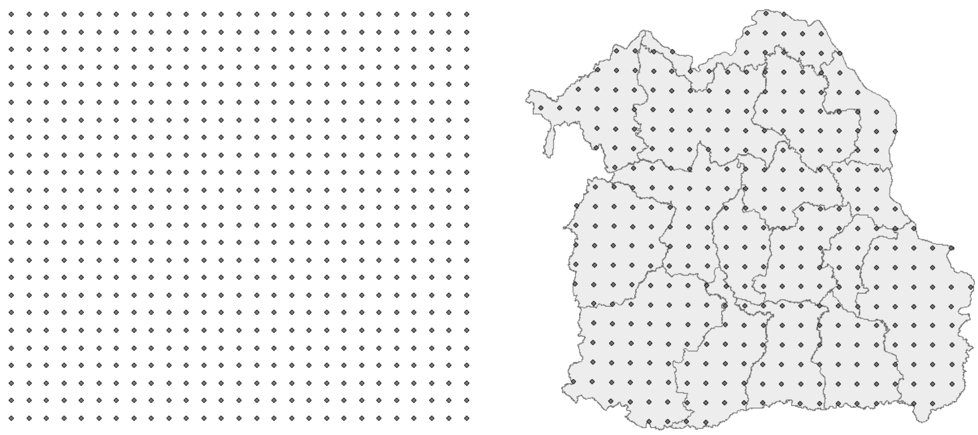


Figure 5.2 Studied-grid of climate change scenarios for NE Thailand

(SEA START RC)

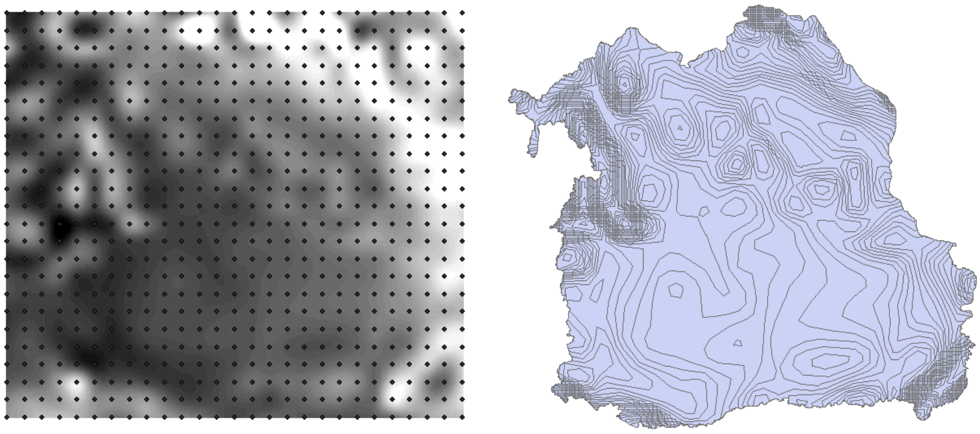


Figure 5.3 Climate Maps using the Spline Interpolation Technique

Source: Author's compilations based upon climate change scenarios from SEA START RC climate change data distribution system

To estimate the monthly and annual area-averaged temperature or precipitation for each province, the same formula as employed with Thiessen Polygons was adopted (equation (13) in chapter 4).

$$\text{Area-averaged climate of each province} = \frac{\Sigma\,(\text{Climate Value x Polygon Area})}{\Sigma\,(\text{Polygon Area})} \qquad (13)$$

Figure 5.4 presents monthly area-averaged climates for NE Thailand over the baseline period (1980-2009) based on climate change scenarios retrieved from SEA START RC climate change data distribution system. In comparison to the observed data from TMD, PRECIS regional climate model over-estimates average maximum temperature in April about 0.58°C and average precipitation in August approximately 43 mm or 17% but under-estimates average minimum temperature in December about 0.18°C.

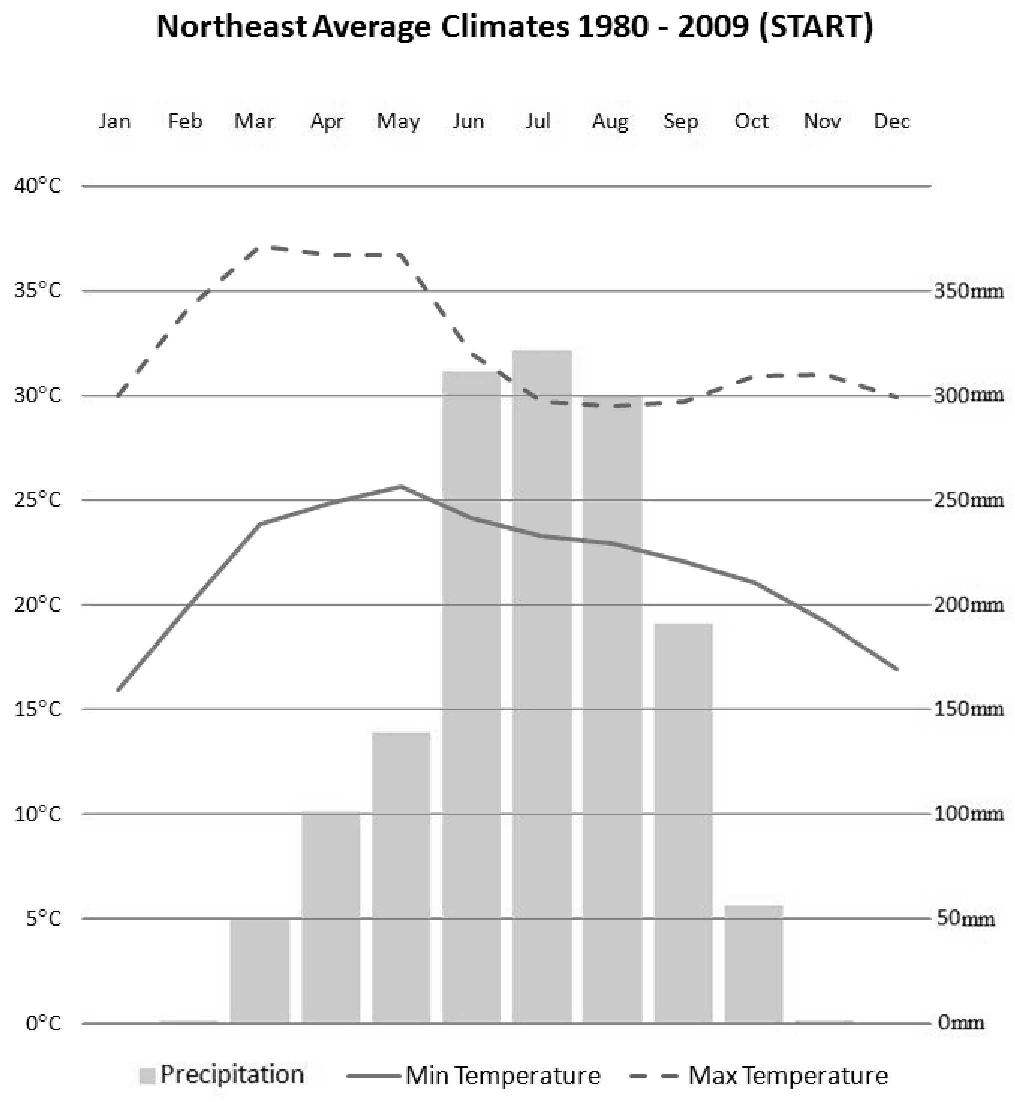


Figure 5.4 Monthly Area-Average maximum temperature, minimum temperature and precipitation for NE Thailand in the baseline period determined from Spline Interpolation analysis of SEA START RC data

In addition, the study applied Two-Sample t-Test to examine whether observed data from TMD and climate change scenarios from SEA START RC over the period 1980-2009 for each of 16 meteorological and 173 hydro-meteorological station, using the same reference Lat./Long., are likely to have come from two underlying populations that have the same mean. The comparisons show that observed maximum temperatures from 14 meteorological stations have the same mean as simulated maximum temperatures from SEA START RC. For the observed minimum temperatures, however, there are only 6 meteorological stations that have the same mean as the simulated minimum temperatures from SEA START RC. In terms of precipitation, observed data from 125 hydro-meteorological stations have the same mean as simulated data. It can be assumed that maximum temperature and precipitation data are samples from populations that have the same mean as observed data.

According to Chinvanno (2009), the rescaled maximum temperature for Thailand and surrounding countries from PRECIS regional climate model is more realistic when compared to observed data, which the different from the observation falls into the range of +/- 1ºC and different in annual precipitation falls within the range of +/- 50 mm/annum while the rescaled minimum temperature is slightly underestimated in some area, especially in the in-land area of the simulation domain, and overestimated in the area near the coastline. The climate change projections for NE Thailand during the baseline period are consistent with the future climate projections for Thailand and surrounding countries. Although there are some differences between the projections and the observed data in the baseline period, particularly minimum temperatures, the result does not show a substantial gap between those two datasets. The climate change scenarios from SEA START RC are therefore highly practicable for an analysis of climate change projections for NE Thailand in 21th century.

5.4 Climate Change Projections for Northeast Thailand

For an analysis of climate change projections for NE Thailand in the 21th century, climate change scenarios were estimated for monthly and annual measures of temperature (°C) and precipitation (mm). Figure 5.5, 5.6 and 5.7 present annual area-averaged maximum temperature, minimum temperature and precipitation of the region under SRES A2 and B2 pathways, respectively, for four 30-year time slices averaged over 1990s, 2020s, 2050s and 2080s. The projections show that future annual area-averaged maximum temperature and minimum temperature in NE Thailand are likely to increase, which tend to be more prominent from the middle of the century onward. The trend of warming temperature is seen clearly in the southern part of the region. The range of future annual area-averaged maximum temperature is approximately 31.21°C to 34.53ºC during the middle of the century and the increasing trend continues until the end of the century when most temperatures in the region are likely to be in the range of 33.72°C to 35.94ºC (see Figure 5.5). From Figure 5.6, one can see that the range of annual-averaged minimum temperature in the future is approximately 20.19°C to 26.50ºC.

Annual total precipitation may fluctuate in the early decades of the century, but the simulation result shows trend of higher precipitation throughout NE Thailand in the future, especially toward the end of the century. The range of annual total precipitation in the future is approximately 1200 mm to 2460 mm during the middle of the century, and may as high as 2665 mm by the end of the century, as can be observed in Figure 5.7.

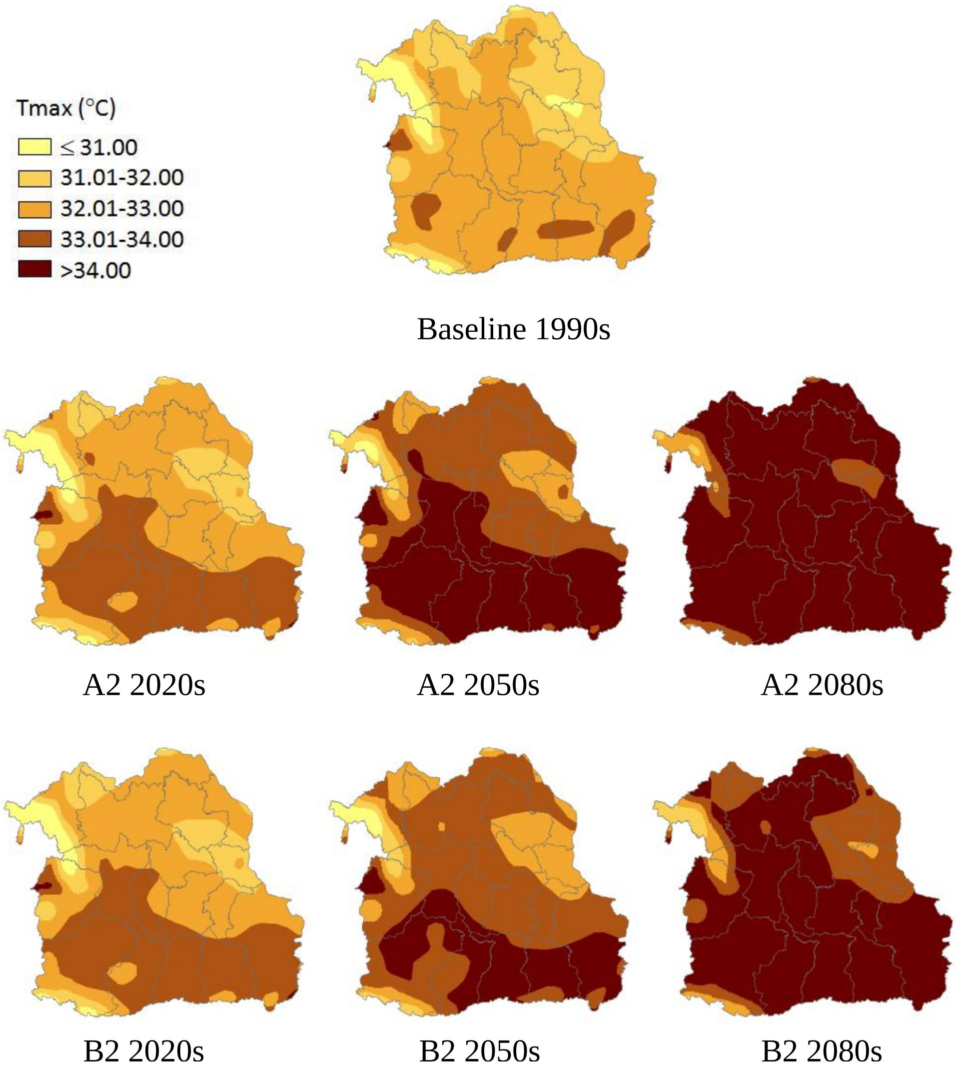


Figure 5.5 Area-Averaged Maximum Temperature of NE Thailand under SRES A2 and B2 pathways for Four 30-Year Time Slices Averaged Over 1990s, 2020s, 2050s and 2080s

Source: Author's compilations based upon climate change scenarios retrieved from SEA START RC climate change data distribution system

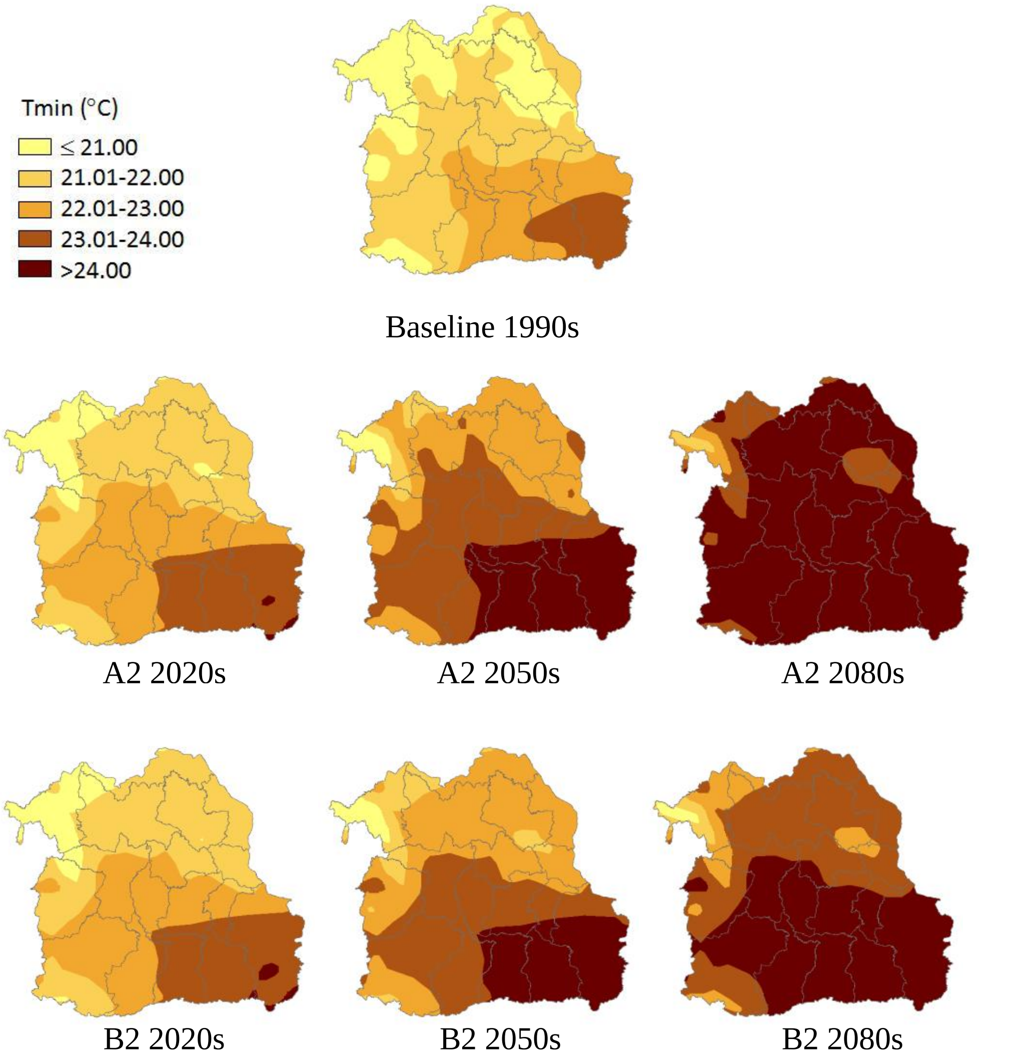


Figure 5.6 Area-Averaged Minimum Temperature of NE Thailand under SRES A2 and B2 pathways for Four 30-Year Time Slices Averaged Over 1990s, 2020s, 2050s and 2080s

Source: Author’s compilations based upon climate change scenarios retrieved from SEA START RC climate change data distribution system

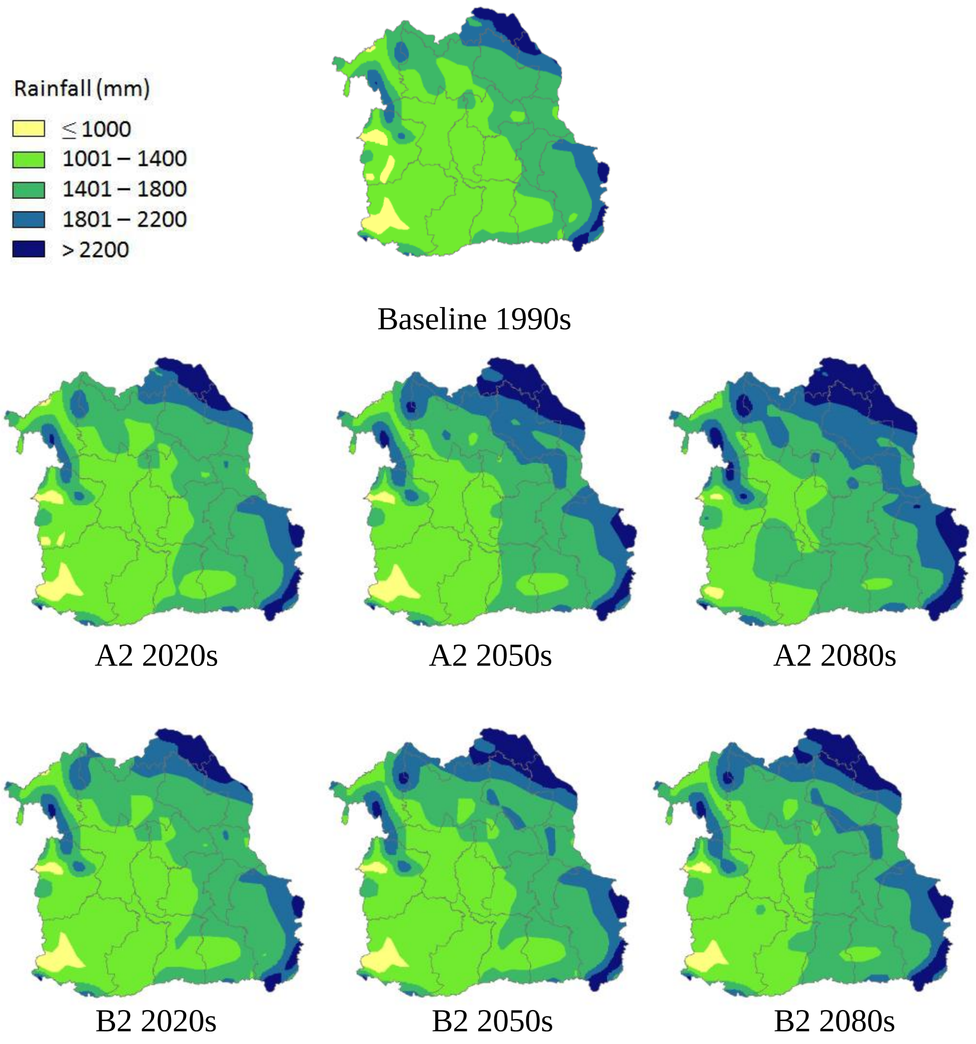


Figure 5.7 Area-Averaged Precipitation of NE Thailand under SRES A2 and B2 Pathways for Four 30-Year Time Slices Averaged Over 1990s, 2020s, 2050s and 2080s

Source: Author's compilations based upon climate change scenarios retrieved from SEA START RC climate change data distribution system

In the early decades of the century (2020s), the annual area-averaged maximum temperatures of NE Thailand under the SRES A2 and B2 GHG scenarios are predicted to increase slightly with reference to the baseline period (1990s). The average maximum temperatures for both the A2 and B2 scenarios are approximately 32.65°C compared with 32.27°C of the baseline period. During the middle of the century (2050s), area-averaged annual maximum temperature projections are likely to increase by 1.23-1.54°C with reference to the 1990s. The regional average maximum temperatures over the 2050s year for the A2 and B2 scenarios are approximately 33.90°C and 33.59, respectively. In Figure 5.5, the projections for NE Thailand annual area-averaged maximum temperature in the 2080s present significant increases in temperature. The figures show that the areas where the annual-averaged maximum temperature is higher than 34°C have spread over more provinces in the region. Si Sa Ket, Surin and Buri Ram provinces are forecasted as the hottest areas of NE Thailand in 2080s, with the annual area-averaged maximum temperatures as 35.94°C, 35.90°C and 35.68°C, respectively.

As with the maximum temperature, the predicted annual area-averaged minimum temperatures are slightly higher than the baseline period, by approximately 0.5°C, for both A2 and B2 scenarios in 2020s (Figure 5.6). Temperatures are moderately higher than the baseline period by 1.84°C for A2 and 1.51°C for B2 scenarios in the 2050s compared with 21.64°C for the 1990s. In the 2080s, more than 80% of areas in the region are likely to experience an annual area-averaged minimum temperature higher than 24°C for the SRES A2 GHG scenario while the SRES B2 GHG scenario projects that around 50% of areas are likely to experience an average of minimum temperature higher than 24°C.

As can be seen from Figure 5.7, the projections of annual total precipitation present an increase in amount of rainfall in many parts of the region. For the A2 scenario, the annual total rainfall is likely to increase from the baseline period of 1480 mm to about 1520, 1620 and 1740 mm for the 2020s, 2050s and 2080s, respectively. With the B2 scenario, the annual total rainfall is predicted as likely to increase to about 1530, 1570 and 1625 mm for 2020s, 2050s and 2080s, respectively. These increases are also likely to increase the risk of flooding in the future, especially the areas bordering the Mekong River such as Nong Khai, Nakhon Panom and Ubon Ratchathani provinces where the annual rainfall is projected more than 2000 mm.

Table 5.2 demonstrates the season-wise projections of the likely change in surface air temperatures and rainfall in NE Thailand under SRES A2 and B2 pathways, again for three time slices with reference to the 1990s. According to Table 5.2, in the 2080s, the projected increase in annual area-averaged maximum temperature over NE Thailand will range between 2.11°C and 2.88°C. The season-wise maximum temperature is expected to increase by 2.35°C - 2.68°C, 2.86°C - 3.62°C and 1.68°C - 2.83°C in summer (using climate data in April), rainy (using climate data in August) and winter (using climate data in December) seasons, respectively, by the end of twenty-first century. In terms of the annual area-averaged minimum temperature, the PRECIS regional climate model predicts the increase between 2.44°C and 3.37°C in the 2080s.

Table 5.2 Projections of likely changes in surface air temperatures and rainfall in NE Thailand under SRES A2 and B2 pathways for three time slices: 2020s, 2050s and 2080s with reference to 1990s baseline period, calculated based upon data from SEA START RC

Region/Province	Month	2020s		2050s		2080s	
		A2	B2	A2	B2	A2	B2
Max Temperature	**Change (°C)**						
Northeast	Summer	0.90	1.67	1.73	1.76	2.35	2.68
	Rainy	0.63	0.89	1.64	2.06	3.62	2.86
	Winter	0.18	-0.14	1.29	0.70	2.83	1.68
	Annual	0.38	0.38	1.54	1.23	2.88	2.11
Min Temperature	**Change (°C)**						
Northeast	Summer	0.83	1.42	2.10	1.87	3.11	2.86
	Rainy	0.63	0.78	1.74	1.70	3.33	2.49
	Winter	0.39	0.04	1.98	1.06	3.72	2.32
	Annual	0.54	0.55	1.84	1.51	3.37	2.44
Rainfall Change (%)							
Northeast	Summer	-8.50	-20.88	2.33	-12.13	19.27	-2.73
	Rainy	7.03	2.44	13.09	3.01	15.31	7.45
	Winter	0.00	0.00	0.00	0.00	0.00	0.00
	Annual	2.63	3.00	9.11	6.09	17.27	9.49

In addition, the summer, rainy and winter seasons area-averaged minimum temperatures over the region are expected to rise between 2.86°C - 3.11°C, 2.49°C - 3.33°C and 2.32°C - 3.72°C, respectively, by the end of twenty-first century.

It may be noted from Table 5.2 that the area-averaged rainfall rise over Northeast is projected the fluctuate in summer rainfall by the end of twenty-first century that expected the region may experience decline in rainfall of 2.73% and increase of 19.27% while the area-averaged rainy rainfall is projected to rise between 7.45% and 15.31%. Additionally, the area-averaged winter rainfall is projected to be largely absent by the end of twenty-first century. The projected increases in area-averaged summer and rainy rainfall are sufficiently large that they may cause devastating floods in NE Thailand. The projected absence of rainfall in wintertime and decline in summer rainfall is likely to be significant and may lead the region experiencing prolonged droughts during the dry winter and summer months.

The highest projected increase in annual area-averaged maximum temperature for an individual province is Sri Sa Ket province in the range of 2.20°C - 3.06°C by the end of twenty-first century, followed by Ubon Ratchathani (2.20°C - 3.04°C), Nong Khai (2.31°C - 3.02°C) and Surin (2.14°C - 2.99°C). The projected annual area-averaged minimum temperature increase is greatest in Loei province in the range of 2.55°C - 3.55°C by the end of twenty-first century, followed by Udon Thani (2.57°C - 3.48°C), Chaiyaphum (2.48°C - 3.43°C) and Nakhon Ratchasima (2.42°C - 3.42°C). By the end of twenty-first century, the area-averaged rainfall increase over provinces in the southern part of NE Thailand such as Buri Ram, Surin, Si Sa Ket and Nakhon Ratchasima provinces, are projected in the range of 5.98% - 10.86%, 8.62% - 11.87%, 9.70% - 12.12%

and 5.30% - 13.93%, respectively, while the increase over areas bordering the Mekong River, such as Nakhon Phanom and Nong Khai as well as the neighbouring provinces such as Sakon Nakhon and Udon Thani provinces, are projected to be 11.63% - 25.24%, 12.17% - 24.22%, 11.26% - 24.22% and 12.73% - 23.72%, respectively (see Appendix Table A58). Notably, provinces bordering the Mekong River are likely to be more prone to serious floods than in-land provinces. By considering the interaction between maximum temperature and rainfall changes, provinces in the southern part of NE Thailand are likely to experience severe droughts than other provinces in the central and northern parts of the region since they are predicted to suffer the greatest increase in annual area-averaged maximum temperature but the least in area-averaged rainfall rise.

Figure 5.8 Areas at risk to severe droughts and floods

Source: Author's compilations

5.5 Discussion

The last decade has seen an attempt to study climate change scenarios for Thailand and some studies have projected the future climate of NE Thailand for the 21st century. In a pilot study of future climate change impact on water resource and rain-fed agriculture production, climate change scenarios for case studies in Lao PDR and Thailand, for example, are generated by the Conformal Cubic Atmospheric Model (CCAM) in three scenarios; 1.0 x CO_2 (CO_2 360 ppm of carbon dioxide) baseline year scenario, 1.5 x CO_2 (CO_2 540 ppm) and 2.0 x CO_2 (CO_2 720 ppm), which are determined to occur during 1980-1989, 2040-2049 and 2066-2075, respectively. The daily maximum temperature in the region is expected to be warmer by 0.5°C and 1°C when the atmospheric CO_2 is raised to 540 ppm and 720 ppm, respectively (Chinvanno and Snidvongs, 2005). Mean rainfall during the wet period could increase by over 30%, at both 540 and 720 ppm CO_2 in Lao PDR. Thailand is expected to be least affected by elevated CO_2 (Chinvanno and Snidvongs, 2005).

Sarawat et al. (2005) studied the potential impact of climate change on maize, sugarcane and cassava production in NE Thailand in Khon Kaen province. The simulation results using climate scenarios 1.5 – 2 x CO_2 derived from CCAM models show a relatively increased maximum temperature of 1-2°C and increased precipitation with reference to 1 x CO_2 scenario (Sarawat et al., 2005).

In addition, the study of NE Thailand futures - a local study of the exploring Mekong region futures - aims to examine appropriate policies for long-term development of NE Thailand (Krittasudthacheewa et al., 2012). According to the country energy policy promoting ethanol and biodiesel, farmers in the region alter their food cropping regime and switch to either sugarcane or cassava. The project explores future farming activities and examines the potential implications to the livelihoods of people in NE Thailand. The study, applies the SRES A2 and B2 regional emission scenarios and expects temperature increases to 3.4°C and 2.4°C, respectively (Krittasudthacheewa et al., 2012).

SEA START RC (2010) studies on climate change scenarios for Thailand during the period of the years 2045-2065 are based on summary from projection of 8 climate models (CCMA CGCM3.1, MPI_ECHAM5, GISS, CNRM_CM3, CSIRO_MK3.0, CSIRO_MK3.5, IPSL_CM4 and GFDL_CM2.0) under moderate projection of greenhouse gas, SRES A1B scenario, and climate scenarios based on simulation by PRECIS RCM using ECHAM4 as initial data for climate change calculations under SRES A2 and B2 scenarios in decadal averages of 2010s, 2050s and 2090s. The results from 8 climate models are summarised in 3 variables; maximum temperature, minimum temperature and annual precipitation and shown by geographic zones in Thailand, including the Northern mountain and valley, Central plain and Chao Phraya River basin, Western region, Mekong River corridor, Northeastern plateau, Eastern region, Lower gulf of Thailand coast and Lower Andaman coast - Phuket.

The climate change scenarios for NE Thailand cover two zones consisting of the Mekong River corridor and the Northeastern plateau zones. According to SEA START RC (2010), range of annual-averaged maximum temperature for Mekong River corridor and Northeastern plateau during 2045-2065 are approximately 34.81°C - 37.35ºC and 35.36°C - 37.84°C with reference to baseline (average over the period of 1961-2000) maximum temperature of 32.09ºC and 32.66ºC, respectively. The range of annual-averaged minimum temperature for Mekong River corridor and Northeastern plateau during 2045-2065 are approximately 24.94°C - 27.12ºC and 25.44°C - 27.59°C, respectively, with reference to baseline minimum temperature of 21.98ºC and 22.55ºC (SEA START RC, 2010). Additionally, the range of annual-averaged precipitation for the Mekong River corridor and Northeastern plateau during 2045-2065 are approximately 1043mm - 2225mm and 779mm - 1564mm, respectively, with reference to baseline precipitation of 1567mm and 1089mm (SEA START RC, 2010).

The simulation result from a PRECIS RCM shows a tendency for the average maximum temperature to increase from approximately 33°C-35°C to 37°C-39°C under the SRES A2 scenario with a lesser extent under the SRES B2 scenario through the century, distributed unevenly throughout the country. SEA START RC (2010) reports a trend of increasing average minimum temperature throughout the 21st century from the range of 22°C-26°C to 26°C-28°C under the SRES A2 scenario, with a lower degree of increase under SRES B2 scenario. Furthermore, simulation results show a clear trend of significantly increased precipitation by the end of the 21st century, particularly in the lower Gulf of Thailand coast, eastern region and Mekong River corridor zones under the SRES A2 scenarios with lesser scale under the SRES B2 scenario (SEA START RC, 2010).

It is clear that the results of climate change scenarios for NE Thailand calculated here confirm the consistent trends of increasing annual-averaged maximum temperature, minimum temperature and annual total precipitation with previous studies. However, it is not practicable to compare the magnitude of changes since the studied time periods, as well as underlying scenarios, are different from one project to the next. For example, the projections of 8 climate models for the middle of the century estimate an average over the 20-year period of 2045-2065 while the results presented in this study estimates an average over the 30-year period of 2040-2069. The projections of a PRECIS RCM in SEA START RC (2010) study calculate climate data in decadal averages of 2010s, 2050s and 2090s but the present study projects climate change scenarios for four 30-year time slices averaged over 1990s, 2020s, 2050s and 2080s.

Previous studies in the region applied a uniform climate projection. It is argued by SEA START RC (2010) that climate change is not uniform over space and time and its impact on bio-physical system varies from place to place. Therefore, it is necessary to understand climate change at the local scale and aim to get site-specific information. Hence, this study will apply a non-uniform of climate projection in the further analysis of impact of climate change on agriculture in NE Thailand.

Chapter 6

Economic Impact of Climate Change on Agriculture in Northeast Thailand

6.1 Introduction

It is believed that the impacts of climate change on food systems are complex, geographically and temporally varied, and are intensely affected by socio-economic environments (Vermeulen et al., 2012). In 2012, agriculture accounted for 3% of the world's GDP (World Bank, 2014). As scientific evidence becomes more convincing that agriculture is susceptible to global climate change (Anwar et al., 2013), it has become ever more important to understand the impacts of climate change on agriculture (Chen et al., 2013). Climate change has both positive and negative economic impacts on agriculture, which may be captured through farmland values or farm-level net revenues (e.g., Mendelsohn et al. 1994; Reinsborough, 2003; Polsky, 2004; Seo et al., 2005; Timmins, 2006, Kabubo-Mariara and Karanja, 2007; Sanghi and Mendelsohn, 2008; Lippert et al., 2009; Mendelsohn et al., 2010; Ahmed and Schmitz, 2011; Passel et al., 2012; Salvo et al., 2013; Masud et al., 2014).

The main research aim of this thesis is to assess the economic impact of climate change and climatic variability on agriculture in NE Thailand. To achieve this aim, this chapter sets out to examine how changing climate variables including temperature and precipitation are impacting the farmers' income in the region, utilising a Ricardian approach and a spatial econometric analysis. The following sections are structured as follows; section 6.2 reviews a wide range of applications of the Ricardian approach; section 6.3 provides results of the descriptive statistic analysis of the panel dataset used in this study; and section 6.4 presents the climate response functions which are the panel regression analyses using farm-level net revenue to understand the impact of climate change on agriculture. Additionally, this study undertook a spatial econometric analysis to estimate the spatial panel models in order to correct for the heteroscedasticity in the spatial analysis. Section 6.5 depicts results of the anticipated climate change impacts on NE agriculture, and section 6.6 discusses the findings of this chapter. The last section provides concluding comments.

6.2 The Ricardian Approach: A Review of its Application in Farming and Climate Change Research

There are a growing number of studies on climate change impacts on agriculture across the world applying the Ricardian approach. The literature consists of research both in developed countries, such as the US (Mendelsohn et al., 1994; Polsky, 2004), Canada (Reinsborough, 2003), Germany (Lippert et al., 2009) and Italy (Salvo et al., 2013), and developing countries, such as China (Wang et al., 2009; Chen et al., 2013), Brazil (Sanghi and Mendelsohn, 2008; Timmins, 2006), Mexico (Mendelsohn et al., 2010), Pakistan (Ahmed and Schmitz, 2011), Sri Lanka (Seo et al., 2005), India (Kumar, 2009), Kenya (Kabubo-Mariara and Karanja, 2007), and Malaysia (Masud et al., 2014), with pan-continental studies of South America (Seo and Mendelsohn, 2008a), Africa (Seo and Mendelsohn, 2008b), Europe (Passel et al., 2012) and Asia (Mendelsohn, 2014).

The Ricardian method was named after David Ricardo, an Italian economist who was the first to note that farm property values reflect the net productivity of the land (Mendelsohn et al. 1994; Gbetibouo and Hassan, 2005; Chen et al., 2013). Mendelsohn et al. (1994) developed the Ricardian method to estimate the impact of climate change on agriculture (Passel et al., 2012; Chen et al., 2013; Musad et al., 2014). The original Ricardian studies and a number of studies for developed countries capture climate impact on agriculture through farmland values. However, in developing countries where land value is not available, annual net revenue per hectare can be alternatively used since land value is the present value of a future stream of net revenue (Dinar et al, 1998; Seo et al., 2005).

Mendelsohn et al. (1994) measure the economic impact of climate on farmland prices using a Ricardian model based on cross-sectional data of almost 3000 counties in the US. Two weights are adopted in the regressions: cropland weights and crop-revenue weights, to represent the importance of each county. Counties with a large fraction of cropland should provide a better reading on price determination while the latter weighting scheme emphasizes those counties that are most important to total agricultural production since they are places where more valuable crops are grown and contribute much to the country's agricultural income (Mendelsohn et al., 1994).

The cropland model used by Mendelsohn et al., 1994 predicts higher winter temperatures will be less harmful, valuing a 1°F increase as 89-103 $/acre; whereas crop-revenue model predicted more harmful effect, with estimated impacts 138-160 $/acre. However, the cropland model and crop-revenue model estimate the decreases of farm values given a 1°F increase in summer as 155-177 $/acre and 88-132 $/acre, respectively (Mendelsohn et al., 1994). In terms of rains, the crop-revenue model predicted that winter rain increases farm values by 172-280 $/monthly inch while the cropland model predicted 57-85 $/monthly inch (Mendelsohn et al., 1994). In addition, Mendelsohn et al. (1994) applied a uniform 5°F temperature increase with 8% increase in precipitation by season and region across the US to project the impact of global warming on American agriculture, revealing that the estimates diverge dramatically depending upon whether cropland or crop-revenue weights were used; projected loss in land value from warming ranges from $119-141 billion under the cropland weight, as opposed to, slightly positive net impact of warming of $20-35 billion in farmland values under the crop-revenue approach.

More recent research by Mendelsohn et al. (2010) measure the impact of climate change on Mexican agriculture using a Ricardian analysis that relies on economic data, climate, elevation, soils and distance to nearest city data from 621 individual farms. The analysis shows that farmland values in Mexico are sensitive to climate; warmer temperatures reduce land value on average by 4,000-6,000 pesos/°C (Mendelsohn et al., 2010). The study also explored how future climate might affect cropland in Mexico using a set of climate change scenarios for 2100 predicted by three climate models: whereby the Centre for Climate System Research (MIMR) predicts an average increase of 5.1◦C and a precipitation reduction of 3.6 mm/month in Mexico, the Hadley Centre for Climate Prediction and Research (HADCM3) predicts a temperature increase of 5.1°C with a small increase of 0.4 mm/month of precipitation, and the Parallel

Climate Model (PCM) predicts a 2.3°C warming and a reduction of 1.7 mm/month in annual precipitation (Mendelsohn et al., 2010). The models predict average losses with all three climate scenarios of between -42% and -50% of land value in Mexico (Mendelsohn et al., 2010).

Gbetibouo and Hassan (2005) highlight that one of the advantages of a Ricardian approach is that it can examine the climate impact on many crops rather than a limited number of major crops and take account for farmer responses to the changing climate. Gbetibouo and Hassan (2005) study the impact of climate change on South Africa’s seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean) using a Ricardian regression of farm net revenue on climate, soil and other socioeconomic variables in 300 districts to capture farmer-adapted responses to climate variations. Results indicate that temperature rise positively affects net revenue whereas the effect of reduction in rainfall is negative (Gbetibouo and Hassan, 2005). The study also highlights the importance of the spatial distribution of climate change impact which requires divergent adaptations across the different agro-ecological regions of South Africa, such as major shifts in crop calendars and growing seasons, switching between crops to the possibility of complete disappearance of some field crops from some regions (Gbetibouo and Hassan, 2005).

Kabubo-Mariara and Karanja (2007) assess the economic impact of climate on crops in Kenya adopting a seasonal Ricardian model based on household level data. Projected temperature increase may have substantial inverse impact on net crop revenue per acre (Kabubo-Mariara and Karanja, 2007). The study suggests that climate change monitoring and information dissemination can encourage farmers to adapt to climate change while improved management and conservation of available water resources, water harvesting and recycling of wastewater could generate water for irrigation purposes especially in the arid and semi-arid areas (Kabubo-Mariara and Karanja, 2007).

A Ricardian model can be exploited to examine the impact of climate change on livestock. Seo and Mendelsohn (2008b) develop a structural Ricardian model to measure impacts and adaptations to climate change of African livestock management using cross-sectional data at district level in Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal and South Africa. The study explores which species African farmers choose (from five major types of livestock in Africa as beef cattle, dairy cattle, goats, sheep, and chickens), how many animals they own, and how net revenue per animal for each species changes. It is a two-stage model; firstly the probability of selecting a species is estimated using the relative prices of each specie choice, and in the second stage, conditional on the choice of a specific species, the optimal number of that species and the net revenue per animal are estimated using the percentage of grassland in the district (Seo and Mendelsohn, 2008b).

By examining a set of climate change scenarios predicted by Atmospheric Oceanic General Circulation Models (AOGCMs) reflecting the A2 SRES scenarios for the years 2020, 2060 and 2100 from the three climate change models: the Canadian Climate Centre (CCC) scenario (Boer et al., 2000), Centre for Climate System Research (CCSR) (Emori et al., 1999), and Parallel Climate

Model (PCM) (Washington et al., 2003), African temperatures are predicted to increase steadily until 2100 (2°C to 6°C) and precipitation may be variable through time: CCC predicts a declining trend; CCSR predicts an initial decrease, and then increase, and decrease again; and PCM predicts an initial increase, and then decrease, and increase again (Seo and Mendelsohn, 2008b).

The African current average income from livestock management is around 900 $/farm or accounts for $60 billion in total (Seo and Mendelsohn, 2008b). An estimate of the aggregate livestock impact across Africa suggests that the damage will vary from a loss of $9 to $12 billion in livestock income in 2020, from zero to a $15 billion loss in 2060, and finally from a loss of $5 billion to a gain of $100 billion in 2100 (Seo and Mendelsohn, 2008b). This analysis reveals that small farmers can switch species and move away from beef cattle, dairy cattle, and chickens toward goats and sheep without much change in expected income but large farms net incomes are predicted to reduce considerably (Seo and Mendelsohn, 2008b).

Additionally, the Ricardian approach can be applied to examine integrated sources of agricultural income. Reinsborough (2003) estimates the effects on Canadian agriculture of possible climate change scenarios using a comparative static Ricardian model. Farm value used in the Reinsborough (2003) study consists of crop, livestock and poultry revenues. Two weighting schemes are applied; farmland weight places emphasis on which agriculture covers a larger share of total land, and farm-revenue weight emphasizes the agricultural production which is the most important in total revenues. Assuming a uniform

2.8°C temperature increase coupled with an 8% increase in precipitation, the farm-revenue weight model predicts $1.5 million benefit whereas farmland weight model predicts $1.0 million (Reinsborough, 2003). In addition, the impacts of non-uniform Canadian climate change scenarios are also explored. Using the CGCM1 GAX model projection of 1.94°C temperature increase coupled with a 2.89% increase in precipitation, farm-revenue weight model predicts $0.8 million benefit whereas the farmland weight model predicts $0.9 million (Reinsborough, 2003). Using the CGCM1 GG1 model projection of 2.38°C temperature increase coupled with a 3.40% increase in precipitation, farm-revenue weight model predicts $0.7 million benefit whereas the farmland weight model predicts $0.6 million (Reinsborough, 2003). As such, Reinsborough (2003) finds that there are insignificant benefits from climate change compared with annual gross Canadian farm revenue of roughly $32 billion.

Accounting for Space

According to Kumar (2009), spatial features can be introduced into the Ricardian approach. Kumar (2009) applies the Ricardian approach to examine the impact of climate change on Indian agricultural farm level net revenue, using panel data over a twenty year period and on 271 districts while accounting for spatial features that may influence the climate sensitivity of agriculture. It is found that climate change results in a 9% decline in agricultural revenues in the base model, but incorporating spatial effects lowers this decline to 3%. Kumar (2009) suggests that better promulgation of knowledge among farmers through both market forces and local leadership would help promote effective adaptation strategies to address climate change impacts.

Lippert et al. (2009) estimate the impact of climate change on German agriculture based on a Ricardian analysis which accounts for spatial autocorrelation. The cross-sectional analysis yields an increase of land rent along with both a rising mean temperature and a declining spring precipitation, except for Eastern Germany (Lippert et al., 2009). The local land rent changes are simulated under three IPCC scenarios; A1B, A2 and B2, performed using data averaged over the 2011-2040 period from the regional climate model REMO. The overall rent increase corresponds to approximately 5-6% of net German agricultural income and it is expected that income losses in the long run when temperature and precipitation changes are more severe (Lippert et al., 2009).

Transformed functions can also be applied with the Ricardian model. Using three functional forms; linear, log linear and Box-Cox specifications, Salvo et al. (2013) applies the Ricardian approach to measure the impact of climate on the agricultural system of a small Italian Alpine region. The study reports a reduction in annual net revenues of farmers growing apples and grapes caused by climate changes. It is also highlighted the advantage of the Ricardian approach which can be applied on a small territorial scale if there is sufficient climatic variation across the sample and suitable control variables are available (Salvo et al., 2013).

Seo et al. (2005) assesses climate change impact on Sri Lanka agriculture also using the Ricardian method. The impacts of rainfall increases are estimated to benefit the country’s agriculture but temperature increases are predicted to be harmful, based on five AOGCM scenarios. The impacts vary between -11 billion rupees (-20%) and 39 billion rupees (+72%) depending on the climate scenarios (Seo et al., 2005). The Northern and Eastern provinces are expected to lose large portions of their current agriculture but the Central highlands are predicted to gain at the current or higher output (Seo et al., 2005).

Sanghi and Mendelsohn (2008) estimate the climate sensitivity of Brazilian and Indian farms using Ricardian method. Annual damages in Brazil between 1% and 39% and between 4% and 26% in India by the end of the next century are projected, although some of this effect may be potentially offset by carbon fertilization (Sanghi and Mendelsohn, 2008).

Wang et al. (2009) analyse the effects of expected changes in climate on Chinese net crop revenues based on cross-sectional data from 8,405 households across 28 provinces. Global warming is likely to damage rainfed farms but benefit irrigated farms (Wang et al., 2009). The net impacts grow over time and vary by region. Farms in the southeast are mildly affected but farms in the northeast and northwest are likely to bear the largest damages (Wang et al., 2009).

Chen et al. (2013) incorporates a Ricardian approach at a cross-provincial level with a multi-level model based on farm-level group data to assess the impact of climate change on China’s agriculture production. The warming temperature has a positive impact on net crop revenue per hectare while increased precipitation has negative effects (Chen et al., 2013). Climate change may generate a potential advantage for Chinese agriculture especially in the provinces of the northeast, northwest and north regions but increased precipitation may lead to a loss in the provinces of southwest, northwest, northern and northeast regions (Chen et al., 2013). At a Chinese national total level, net crop revenue is projected to increase between 79 $/ha to 207 $/ha for the 2050s, and further increase from 140 $/ha to 355 $/ha for the 2080s (Chen et al., 2013).

Mendelsohn (2014) adopts the Ricardian study of China (Wang et al., 2009), which estimated climate coefficients for Chinese crops to interpolate potential climate change impacts on agriculture in Asia. The model predicts small aggregate effects with a 1.5°C warming but a 3°C warming may cause damages as high as $84 billion and India is expected to be highly vulnerable (Mendelsohn, 2014).

Passel et al. (2012) apply a continental scale Ricardian analysis to estimate the impact of climate on European agriculture using farmland values of 37612 individual farms across the EU-15. The marginal effects differ a great deal across countries within the EU-15. Annual temperature has a beneficial marginal effect on Austria, Belgium, Germany, Denmark, Finland, Ireland, Luxembourg, Netherlands, Sweden and Great Britain but has a negative marginal effect on Spain, Greece, Italy and Portugal (Passel et al., 2012). The magnitude of the marginal effects varies by countries, for example, Sweden and Finland gain the highest benefit about 9% of land value per °C while Spain, Greece, Italy and Portugal lose about 10% of land value per °C. According to Passel et al. (2012), increased annual precipitation is beneficial to Austria, Belgium, France, Germany, Greece, Italy, Luxembourg, Portugal and Spain but harmful to

Denmark, Finland and Sweden while has no significant effect on Ireland, the Netherlands and Great Britain. Portugal, France and Spain gain about 6% of land value per cm/month but Finland loses about 5% of land value per cm/month.

Musad et al. (2014) examine how climate change affects the net income of paddy farmers in Kedah, Malaysia using a Ricardian model and farm household data. The study focuses on sharecropper adaptations and ecological causes. Minimally warmer temperatures are shown to increase net revenue by 4.87 RM/ha during the main season but decrease net revenue by 3.02 RM/ha during off seasons (1 Ringgit Malaysia = $0.3277) (Musad et al., 2014). Increased rainfall, however, affects higher net revenue by 1.32 RM/ha during the off season but lower net revenue by 1.01 RM/ha during the main season.

6.3 Descriptive Statistics

As noted, similar to the literature reviewed above, this thesis uses a Ricardian framework to examine how changing climate variables including temperature and precipitation are impacting the farmers' income in NE Thailand. This study applied spatial panel data analysis to estimate the climate response function and uses the estimated climate coefficients to predict the impacts due to climate change on agriculture. The panel dataset consists of cross-sectional data of 17 provinces in the region and time-series data cover 1984-2010 period. In the dataset, many variables including the dependent variable (farm-level net revenue) and a number of control variables vary from year to year but climate and soil variables vary only across the cross-section. The soil variables were included in the model specification mainly to control for the influence of cross-sectional variability of soil quality on the dependent variable. In terms of climate, Kumar (2009) states that although the weather may change, climate is not expected to change annually. Additionally, the pronounced short-term variability of weather condition makes agricultural production in any given year unpredictable (Lockeretz, 1978; Bowden et al. 1981; Wilhite, 2003).

Table 6.1 summarises the descriptive statistics of the dataset utilised in the study. The average farm level net revenue is around 1450 $/ha but there are large differences between provinces; Loei province has the highest net revenues while Udon Thani, Roi Et and Maha Sarakham provinces have experienced losses since 2000 (see the Appendix Table A1). Most of losses were the results of higher costs of para rubber and longrans productions (see the Appendix Table A2, A11, A14, A15). Loei province is located at the upper west of the NE Thailand. This province earns a high income from agriculture as many of the crops grown there are particularly high value crops, such as potato, orange and pine apple (see the Appendix Table A12, A30).

There are five soil orders spread throughout NE Thailand. Ultisols covers approximately 50% of the total area, followed by Alfisols about 30%, Inceptisols about 10%, and the remainder are Oxisols and Vertisols (see the Appendix Table A53). Ultisols consists of many soil series; for example, Roi Et series (Re), Chakkarat series (Ckr), Phen series (Pn), Tha Yang series (Ty), Phon Phisai series (Pp) and Lat Ya series (Ly). These soil series have poor fertility, and mainly contain loamy sand or sandy clay loam which are moderately well to well drained, exposed to water shortage for plants in the growing season and vulnerable to erosion (Office of Soil Survey and Land Use Planning: OSL, undated).

Table 6.1 Descriptive Statistics

Variables	Min	Max	Average	sd
Net Revenue (USD/ha)	-1970.00	10689.10	1449.10	1832.31
Summer precipitation (mm)	5.47	231.17	79.55	42.02
Rainy precipitation (mm)	57.28	682.30	281.27	121.69
Winter precipitation (mm)	0.00	50.46	2.86	7.18
Summer precipitation sq.	29.86	53441.23	8090.64	8868.40
Rainy precipitation sq.	3281.00	465540.00	93889.00	80735.32
Winter precipitation sq.	0.00	2546.43	59.67	254.49
Summer temperature (°C)	32.02	39.58	36.11	1.34
Rainy temperature (°C)	30.35	34.00	32.11	0.66
Winter temperature (°C)	26.02	33.28	29.71	1.40
Summer temperature sq.	1025.00	1566.00	1306.00	96.71
Rainy temperature sq.	921.00	1156.00	1032.00	42.27
Winter temperature sq.	677.30	1107.40	884.30	82.96
Summer TxR	211.40	8075.60	2834.00	1419.44
Rainy TxR	1874.00	21314.00	8987.00	3781.85

Variables	Min	Max	Average	sd
Winter TxR	0.00	1479.46	85.35	213.06
Population density per ha	0.44	1.79	1.24	0.33
Irrigated land (%)	0.91	13.54	6.06	3.11
Literate population (%)	97.19	100.00	99.74	0.23
FarmHousehold own bullock (%)	1.05	99.34	35.30	29.45
FarmHousehold own tractors (%)	0.46	48.20	23.24	13.99
FarmHousehold own cultivators(%)	0.01	3.23	0.92	0.76
Alfisols soil order area (%)	7.77	68.36	26.91	17.49
Inceptisols soil order area (%)	0.03	26.20	8.77	8.00
Oxisols soil order area (%)	0.00	15.11	1.76	3.61
Ultisols soil order area (%)	12.49	77.99	50.25	20.33
Vertisols soil order area (%)	0.00	5.85	1.48	1.75

Source Author's calculations based upon a comprehensive provincial dataset for NE Thailand

Note 1 sq. = squared term

Note 2 TxR = Temperature multiplied by Rainfall

Vertisols are moderate fertility soils, mainly containing heavy clay and clay which are poorly drained. They are used for paddy fields and provide high productivity. The Buri Ram series (Br), Si Song Khram series (Ss), Thung Samrit series (Tsr), and Lop Buri series (Lb) are the members of Vertisols (OSL, undated). Inceptisols are poor to moderate fertility soils, mainly containing silty clay and clay, which are poorly drained. The Maha Phot series (Ma), Bangkok series (Bk), Sapphaya series (Sa) and Si Thon series (St) are the members of Inceptisols (OSL, undated).

Alfisols include, for instance, Hang Dong series (Hd), Tha Tum series (Tt), Mae Sai series (Ms), Khao Yoi series (Kyo), Kula Ronghai series (Ki), Ubon series (Ub), Si Khiu series (Si) and Muak Lek series (Ml). Alfisols are poor to moderate fertility soils, mainly containing silty clay loam and clay, which are poorly to moderately well drained, and are found in the plains or in the bottom of hills or mountains (OSL, undated). While Oxisols are moderate fertility soils, mainly containing silt loam and clay loam which are moderately well to well drained, suitable for field crops and fruit trees (OSL, undated). Oxisols comprise the Tha Mai series (Ti), Pak Chong series (Pc) and Loei series (Lo), for example. As can be seen from figure 4.2, Alfisols and Oxisols are major soils covering Loei province. These soils enable the farmers in Loei province to diversify their products and earn more income.

NE Thailand has average population density of 1.24 persons/ha; the lower northeast (Surin, Sri Sa Ket, Buri Ram) and the central northeast (Maha Sarakham, Khon Kaen and Kalasin) show high population density, whereas Loei, Mukdahan and Chaiyaphum provinces have low population density (see the Appendix Table A47). About 99% of NE Thailand people understand and have ability to read and write Thai language as well as simple computation (see the Appendix Table A49). Thai farmers widely used bullocks to plough their paddy fields in the past, however nowadays small tractors or walking tractors are more popularly used for paddy field preparation (see the Appendix Table A50, A51). There are a small but growing number of farm households in NE Thailand that own cultivators or large tractors (see the Appendix Table A52).

6.4 Climate Response Function

The Ricardian model is traditionally examined throughout a single cross section (Massetti and Mendelsohn, 2011). The single cross-sectional dataset is the average of the data over the entire period of analysis (1984-2010). In order to estimate the farm-level net revenue per hectare (NR) in equation (11) in chapter 4, the independent variables include the physical climatic variables (three seasonal temperatures and rainfalls) and the other control variables, such as the percentage of literate population, population density, the fraction of area under irrigation, the number of holdings with bullocks, small tractors or walking tractors, cultivators or large tractors per hectare and the fraction of area under five soil orders (alfisols, inceptisols, oxisols, ultisols and vertisols). Thus, there are 26 variables in the equation. As there are 17 provinces in the dataset, the single cross-sectional dataset, therefore, consists of 17 observations. Hence, it is unable to estimate the dependent variable, NR, since the numbers of observations are less than the independent variables mention above.

To overcome this problem, Ricardian approach has evolved to allow estimation with panel data (Massetti and Mendelsohn, 2011; Fezzi and Bateman, 2012). In using this method, one applies repeated observations on agricultural values from the same geographical locations over time to examine the relationship between a farm's profitability and climate characteristics (Polsky, 2004). Massetti and Mendelsohn (2011) compare the results of the repeated cross-section models to measure the impacts of climate change on American agriculture with the results from two panel data approaches; a two stage model by Cheng Hsiao (2008) and a single stage 'pooled' model. They argue that repeated cross sections are mis-specified while both panel data approaches yield stable results and the pooled model givens the best results (Massetti and Mendelsohn, 2011).

Therefore, this study uses panel data approach to estimate the Ricardian model as specified in equation (11) in chapter 4. In addition, this thesis takes account of the spatial nature of the panel data used. The focus is on the inefficiency created by the possible presence of spatial correlation in the error terms of the linear regression models. Kumar (2009) states that given the scope for the presence of unobserved variables that could confound with climate variables, it is possible to employ the spatial fixed effects specification for efficient estimation. This specification, however, would knock out the climate coefficients which are invariant over time. Therefore, the year fixed effect specification is included to capture temporal effects and allow time-invariant variables to be estimated.

This study initially carries out fixed effects error models (both the unit, as province in this case, and the year fixed effects), fixed effects lag model and random effects model using R language plm package. However, as the fixed effects lag model shows very low goodness of fit (adjusted R^2) of 1.55%, this model is then omitted from the analysis. Furthermore, the random effects model could not be estimated in the spatial panel data analysis because of the limited number of observations. The random effects model is also excluded from the analysis. These models are reported in the Appendix Table A78. Thus, the fixed effect model was used as the basis for this analysis.

This study assessed the evidence for spatial autocorrelation of variables (and errors) by running the panel data regression models including the province fixed effects error model and the year fixed effects error model in order to obtain the residuals. The Durbin-Watson test was applied to test for serial correlation in panel models. Durbin-Watson *d* statistic is defined as (Gujarati and Porter, 2009):

$$d = \frac{\Sigma_{t=2}^{t=n}(\hat{u}_t - \hat{u}_{t-1})^2}{\Sigma_{t=2}^{t=n} \hat{u}t2} \qquad (1)$$

The fixed effects error model estimations are shown in Table 6.2. The climate coefficients in summer are statistically significant as well as some other control variables with about 30% goodness of fit in both province and year fixed effects error models. The F-test values for both models are statistically significant. It is found that the temperature affects the farm-level net revenue more than the precipitation.

Table 6.2 Climate Response Function – Fixed Effects Error Models

calculated based upon a comprehensive provincial dataset for NE Thailand

Variable	**Fixed Effects Error Models**	
	Province	**Year**
R_summer	207.0(1.66).	240.3(2.17)*
R_rainy	-0.9(-0.02)	21.3(0.45)
R_winter	-366.6(-1.22)	-284.3(-0.95)
R_summer sq.	-0.1(-2.22)*	-0.1(-1.96)
R_rainy sq.	0.006(1.16)	0.006(1.18)
R_winter sq.	-0.5(-0.68)	0.2(0.28)
Tx_summer	807.9(0.19)	8648.7(2.07)*
Tx_rainy	-13456.0(-1.18)	11346.0(0.99)
Tx_winter	319.8(0.19)	3898.9(1.69).
Tx_summer sq.	-10.8(-0.20)	-114.8(-2.06)*
Tx_rainy sq.	213.1(1.23)	-185.2(-1.07)
Tx_winter sq.	-5.1(-0.18)	-61.6(-1.62)
TxR_summer	-5.1(-1.57)	-6.1(-2.07)*
TxR_rainy	-0.1(-0.08)	-0.8(-0.59)
TxR_winter	13.7(1.38)	9.7(0.97)
Population density	6724.8(3.18)**	-18.1(-0.04)
Irrigated land	258.2(2.44)*	153.4(3.96)***

Variable	Fixed Effects Error Models			
	Province		Year	
Literacy	1149.1(2.68)**		136.9(0.33)	
Bullocks	67.4(6.40)***		54.1(6.94)***	
Tractors	106.6(4.45)***		72.9(3.33)***	
Cultivators	129.4(0.57)		-1713.7(-6.43)***	
Alfisols			11.9(0.44)	
Inceptisols			17.2(0.72)	
Oxisols			463.0(8.75)***	
Ultisols			42.7(1.57)	
Vertisols			609.2(8.41)***	
Intercept	nm	65214(0.31)	1984	-419547(0.04)*
	br	62932(0.30)	1985	-419652(0.04)*
	sr	60570(0.29)	1986	-419121(0.04)*
	ss	62128(0.30)	1987	-417773(0.04)*
	ub	64707(0.31)	1988	-418919(0.04)*
	ys	62547(0.30)	1989	-418842(0.04)*
	cp	68901(0.33)	1990	-418120(0.04)*
	kk	60983(0.29)	1991	-418647(0.04)*
	ud	64816(0.31)	1992	-418465(0.04)*
	lo	71550(0.34)	1993	-418721(0.04)*

Variable	Fixed Effects Error Models			
	Province		Year	
	nk	65049(0.31)	1994	-418730(0.04)*
	mk	58510(0.28)	1995	-417015(0.04)*
	re	59412(0.28)	1996	-414798(0.04)*
	ks	61353(0.29)	1997	-416255(0.04)*
	sk	64830(0.31)	1998	-414551(0.04)*
	np	64624(0.31)	1999	-415071(0.04)*
	mh	67494(0.32)	2000	-417165(0.04)*
			2001	-415921(0.04)*
			2002	-416409(0.04)*
			2003	-415755(0.04)*
			2004	-416125(0.04)*
			2005	-415864(0.04)*
			2006	-415697(0.04)*
			2007	-414441(0.04)*
			2008	-412326(0.04)*
			2009	-411558(0.04)*
			2010	-413996(0.04)*
Observations	459		459	
Adjusted R^2	0.3450		0.2870	

Variable	Fixed Effects Error Models	
	Province	**Year**
F stat. (p-value)	12.09(0)***	7.50(0)***
d stat. (p-value)	0.97(0)***	1.99(0.5015)

Note1: Values in the parentheses are *t*-statistics;

Note2: Significance codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Note3: nm: Nakhon Ratchasima, br: Buri Ram, sr: Surin, ss: Si Sa Ket, ub: Ubon Ratchathani, ys: Yasothon, cp: Chaiyaphum, kk: Khon Kaen, ud: Udon Thani, lo: Loei, nk: Nong Khai, mk: Maha Sarakham, re: Roi Et, ks: Kalasin, sk: Sakon Nakhon, np: Nakhon Phanom and mh: Mukdahan

In the province fixed effects error model, the squared term for the summer precipitation is significant, implying that the observed relationship between summer precipitation and farm-level net revenue is non-linear. The squared term is negative, implying that there is an optimal level of summer precipitation and that either more or less summer precipitation will decrease net revenues. Some socio-economic variables, including population density, irrigated land, literate population, households own bullocks and small tractors, are statistically significant and were found to be beneficial to farmers' income.

In the year fixed effects error model, the squared term for the summer temperature coefficient is negative and statistically significant, implying that the observed relationship between summer temperature and farm-level net revenue is non-linear and there is an optimal level of a summer temperature from which the net revenue function decreases in both directions. The summer precipitation coefficient is positive and statistically significant, implying that an increasing summer precipitation positively affects farm-level net revenue. Some control variables including irrigation areas, households own bullocks, small tractors and cultivators, and Vertisols soil areas are statistically significant. These variables, except farm households own cultivators, are positively associated with farm-level net revenue.

After the Durbin-Watson test rejected the null hypothesis, it can be implied that the province fixed effect error model produces biased estimates. The study attempted to correct for the estimates. Schlenker et al. (2006) and Kumar (2009) suggest spatial features to improve efficient estimates of regression coefficients. One of crucial inputs that spatial analysis needs is the spatial weight matrix W which provides a structure to the assumed spatial relationships (Kumar, 2009).

The weight matrix used in this study is contiguity-based spatial weight. There are two criteria of the contiguity-based spatial weight; a rook weights matrix and a queen weights matrix. The rook weights matrix defines a location's neighbours as those areas sharing a common boundary while the queen criterion determines neighbouring units as those that have any point in common, including both common boundaries and common corners (Anselin, 2005). Therefore, the number of neighbours for any given unit according to the queen criterion will be equal to or greater than that using the rook criterion. In the case of NE Thailand, the rook and the queen weights matrices give the same results of number of neighbours for each province.

The study carried out a spatial econometric analysis in GeoDa and R software. The GeoDa software is adopted to generate the rook weights matrix for NE Thailand provinces. The resulting GAL format spatial weights file is then an input to estimate the spatial panel models using the splm package in R Language as it provides scope for reading the GAL format spatial weights matrix. Table 6.3 presents climate response function – fixed effects error models with spatial correction. This is the attempt to correct for heteroscedasticity in the spatial analysis by accounting for spatial dependence in the data.

Table 6.3 Climate Response Function – Fixed Effects Error Models with Spatial Correction

Variable	Spatial Panel Fixed Effects Error Model	
	Province	**Year**
R_summer	199.8(1.74).	237.2(2.28)*
R_rainy	40(0.81)	14.6(0.32)
R_winter	-129.5(-0.41)	-326.7(-1.21)
R_summer sq.	-0.1(-1.5)	-0.1(-2.22)*
R_rainy sq.	0.002(0.37)	0.007(1.46)
R_winter sq.	-0.2(-0.21)	0.3(0.41)
Tx_summer	2187.6(0.51)	8838.4(2.31)*

Variable	Spatial Panel Fixed Effects Error Model	
	Province	**Year**
Tx_rainy	6123.5(0.52)	8967(0.85)
Tx_winter	1409.5(0.69)	3985(1.91).
Tx_summer sq.	-29.7(-0.52)	-117.6(-2.31)*
Tx_rainy sq.	-88.4(-0.5)	-149.2(-0.93)
Tx_winter sq.	-23.8(-0.7)	-63.4(-1.84).
TxR_summer	-5.2(-1.71).	-6.1(-2.17)*
TxR_rainy	-1.3(-0.9)	-0.7(-0.48)
TxR_winter	5(0.48)	11(1.22)
Population density	4479.1(2.02)*	-21.5(-0.06)
Irrigated land	350.7(3.39)***	152.6(4.17)***
Literacy	659.8(1.71).	179.9(0.45)
Bullocks	61(5.65)***	54.6(7.59)***
Tractors	106.2(4.52)***	72.7(3.57)***
Cultivators	-100.9(-0.42)	-1724(-6.87)***
Alfisols		8.8(0.33)
Inceptisols		13.4(0.58)
Oxisols		464.2(9.22)***
Ultisols		40(1.52)
Vertisols		607(8.92)***

Variable	Spatial Panel Fixed Effects Error Model			
	Province		Year	
Intercept	nm	-241339(0.01)	1984	-388452(0.99)
	br	-243568(0.00)	1985	-388564(0.99)
	sr	-245484(-0.01)	1986	-387990(0.99)
	ss	-244160(-0.01)	1987	-386681(1.00)
	ub	-242274(0.00)	1988	-387835(0.99)
	ys	-244376(-0.01)	1989	-387697(0.99)
	cp	-238781(0.02)	1990	-386969(0.99)
	kk	-245536(-0.01)	1991	-387478(0.99)
	ud	-241977(0.01)	1992	-387210(0.99)
	lo	-236781(0.03)	1993	-387626(0.99)
	nk	-242147(0.01)	1994	-387546(0.99)
	mk	-247632(-0.02)	1995	-385879(1.00)
	re	-247373(-0.02)	1996	-383665(0.99)
	ks	-246083(-0.02)	1997	-385041(1.00)
	sk	-242691(0.00)	1998	-383392(0.99)
	np	-242457(0.00)	1999	-383953(0.99)
	mh	-240585(0.01)	2000	-385917(1.00)
			2001	-384699(1.00)
			2002	-385162(1.00)

Variable	Spatial Panel Fixed Effects Error Model		
	Province	Year	
		2003	-384573(1.00)
		2004	-384924(1.00)
		2005	-384710(1.00)
		2006	-384506(1.00)
		2007	-383211(0.99)
		2008	-381152(0.98)
		2009	-380360(0.98)
		2010	-382769(0.99)

Source: Author's Calculations based upon a comprehensive provincial dataset for NE Thailand

Note1: Values in the parentheses are *t*-statistics;

Note2: Significance codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Note3: nm: Nakhon Ratchasima, br: Buri Ram, sr: Surin, ss: Si Sa Ket, ub: Ubon Ratchathani, ys: Yasothon, cp: Chaiyaphum, kk: Khon Kaen, ud: Udon Thani, lo: Loei, nk: Nong Khai, mk: Maha Sarakham, re: Roi Et, ks: Kalasin, sk: Sakon Nakhon, np: Nakhon Phanom and mh: Mukdahan

Consistent with the above coefficients in the basic Ricardian model using panel data, temperature affects the farm-level net revenue more than the precipitation.

Most of the climate coefficients in the province spatial panel fixed effects error model are insignificant while the summer climate coefficients in the year spatial panel fixed effects error model are statistically significant. In addition, the climate coefficients have the same sign and the same order of magnitude between the year fixed effects error model (Table 6.2) and the year spatial panel fixed effects error model (Table 6.3) but the coefficients are not identical.

In the provincial spatial panel fixed effects error model, the summer precipitation is significantly positive, implying that increasing summer precipitation is profitable to farmers' income. Consistent with the above province fixed effects error model, socio-economic variables such as population density, irrigated land, literate population, households own bullocks and small tractors are statistically significant and are beneficial to farm-level net revenue.

In the year spatial panel fixed effects error model, the squared terms for the summer precipitation and summer temperature are statistically significant and negative, implying that the observed relationship between summer precipitation and farm-level net revenue is non-linear as well as the observed relationship between summer temperature and farm-level net revenue. The negative quadratic coefficient of summer temperature implies that the warmer temperature in summer is beneficial to farm-level net revenue at the first stage then peaking at the optimal level of summer temperature, finally it is harmful to farm-level net revenue as temperatures increase too high. Consistent with the summer temperature, the negative quadratic coefficient of summer precipitation implies that the increasing rainfall is firstly beneficial to NE Thailand farmer income but is harmful if beyond the optimal level of summer precipitation. Some control variable coefficients including irrigated land, households own bullocks and small tractors, the fraction of areas under Oxisols and Vertisols soils are statistically significant and are positively associated with farm-level net revenue but the households own cultivators coefficient affects negatively NE Thailand farmers' revenue.

To check for model accuracy, the study compared estimated and observed farm-level net revenue for each observation covers 17 provinces over the period 1984-2010 in NE Thailand panel dataset using coefficients from climate response function – fixed effects error models with spatial correction in Table 6.3 (see the Appendix Table A70 and A71) and calculated the percentage difference between estimated and observed values for the two model specifications; the province spatial panel fixed effects error model and the year spatial panel fixed effects error model as shown in Table 6.4. In addition, the study compared estimated and observed farm-level net revenue for NE Thailand using the same coefficients as above at the provincial level but calculated with the averaged values of all provinces in the region to be the represent values for NE Thailand. The comparisons are presented in Table 6.5.

Considering the mean values, both spatial fixed effects error models slightly underestimate farm-level net revenues. However, examining the median values, both models are likely to overestimate net revenues. With regard to the choice between the two spatial models; the year spatial fixed effects error model is preferred over the province spatial fixed effects error model since the percentage difference between estimated and observed farm-level net revenue for NE Thailand calculated by the former model is less with reference to the latter model (see Table 6.5).

Table 6.4 Difference between observed and estimated farm-level net revenues (USD/ha) in absolute values and in percentage

Statistics	Observed	Estimated			
		Province	%	Year	%
Mean	1449.1	1444.9	-0.3	1446.7	-0.2
Median	760.5	1341.6	76.4	1219.5	60.3
Minimum	-1970.0	-2412	22.4	-1332.1	-32.4
Maximum	10689.1	5024.2	-53.0	7269.4	-32.0
Standard deviation	1832.3	1174.0	-35.9	1436.0	-21.6

Source: Author's Calculations

The study also applied a t-Test for Paired Two Sample for Means to determine whether two samples, the observed and estimated farm-level net revenue using the year spatial panel fixed effects error model, are likely to have come from the same two underlying populations that have the same mean. Since t-Stat (0.044) is less than t-Critical two-tail (1.97), it is accepted that the observed farmer's income has come from population that has the same mean as the estimations of the farmer's income calculated from the model. It can be inferred that the year spatial panel fixed effects error model has a predictive capacity and can be used to estimate the farmer's future incomes under the two climate change scenarios for NE Thailand, SRES A2 and B2, for year 2020s, 2050s and 2080s.

Table 6.5 Percentage difference between observed and estimated farm-level net revenue using coefficients from the spatial fixed effects error models in Table 6.3 for NE Thailand.

Year	Observed NR	Estimated NR using Province spfem		Estimated NR using Year spfem	
	(USD/ha)	(USD/ha)	% Difference	(USD/ha)	% Difference
1984	160	-335	-588.0	158	-1.5
1985	-17	387	-396.8	-19	12.9
1986	-20	362	-344.9	-22	11.2
1987	186	292	98.2	184	-1.2
1988	325	902	287.1	323	-0.6
1989	399	540	59.0	397	-0.6
1990	481	666	36.7	478	-0.5
1991	719	712	-1.8	716	-0.4
1992	470	713	90.6	467	-0.7
1993	877	1575	272.5	875	-0.3
1994	916	1231	49.2	914	-0.3
1995	1799	1282	-62.7	1796	-0.2
1996	4230	3126	-147.0	4229	0.0
1997	2743	2335	-78.2	2741	-0.1
1998	2563	1423	-479.3	2560	-0.1

Year	Observed NR (USD/ha)	Estimated NR using Province spfem (USD/ha)	Estimated NR using Province spfem % Difference	Estimated NR using Year spfem (USD/ha)	Estimated NR using Year spfem % Difference
1999	2500	2580	3.3	2498	-0.1
2000	1389	2558	57.6	1388	-0.1
2001	1451	1251	-11.8	1448	-0.2
2002	1711	1461	-17.1	1708	-0.1
2003	994	1833	103.8	992	-0.2
2004	1096	2003	171.9	1093	-0.2
2005	1104	1952	208.9	1102	-0.2
2006	1445	2296	1838.5	1443	-0.1
2007	2045	1574	-108.3	2043	-0.1
2008	3840	2606	-150.2	3838	-0.1
2009	4033	2340	-121.7	4031	0.0
2010	1687	1425	31.2	1684	-0.2

Source Author's calculations

Note 1 spfem = spatial panel fixed effects error model

6.5 Projected Climate Change Impacts on NE Thailand Agriculture

In order to gain insight into the influence of various climate change scenarios on agriculture in NE Thailand, this study assessed the impacts based on the preferred estimated climate response function: the year spatial fixed effects error model. The study estimated the climate change-induced impacts through changes in the net revenue triggered by the changes in the climate variables along with other control variables. The study applied specific climate change scenarios for NE Thailand that incorporate non-uniform changes in temperature and precipitation across regions.

According to climate change scenarios for NE Thailand under SRES A2 and B2 pathways for three 30-year time slices: 2020s, 2050s and 2080s with reference to baseline period 1990s, as studied in chapter 5, the expected climate trends are increasing annual-averaged maximum temperature, minimum temperature and annual total precipitation in the region. The projected annual area-averaged climates for each province are presented in the Appendix Table A54 and the projected seasonal area-averaged rainfall, maximum temperature and minimum temperature for each province are shown in the Appendix Table A55, A56 and A57, respectively.

The projected farm-level net revenue by province corresponding to projected climate change scenarios for NE Thailand, holding other factors constant, are reported in the Appendix Table A75. Figure 6.1 depicts farm-level net revenue in 2010 for provinces in NE Thailand. The study considers the 2010 net revenue mainly to accommodate a comparison with the projected net revenue in the

2020s, 2050s and 2080s. Figure 6.2 presents the distribution of climate change impacts at the province level under the SRES A2 and B2 for three 30-year time slices averaged the over 2020s, 2050s and 2080s.

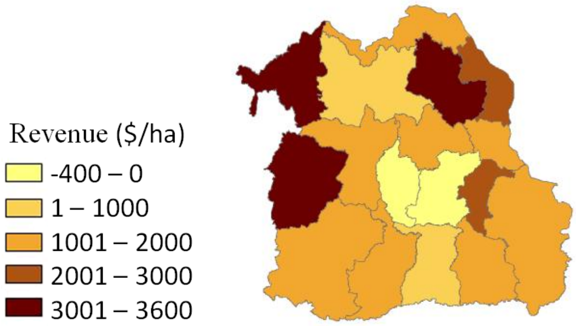


Figure 6.1 Farm-Level Net Revenue in 2010 for Provinces in NE Thailand ($/ha)

Source Author’s compilations based upon data from OAE

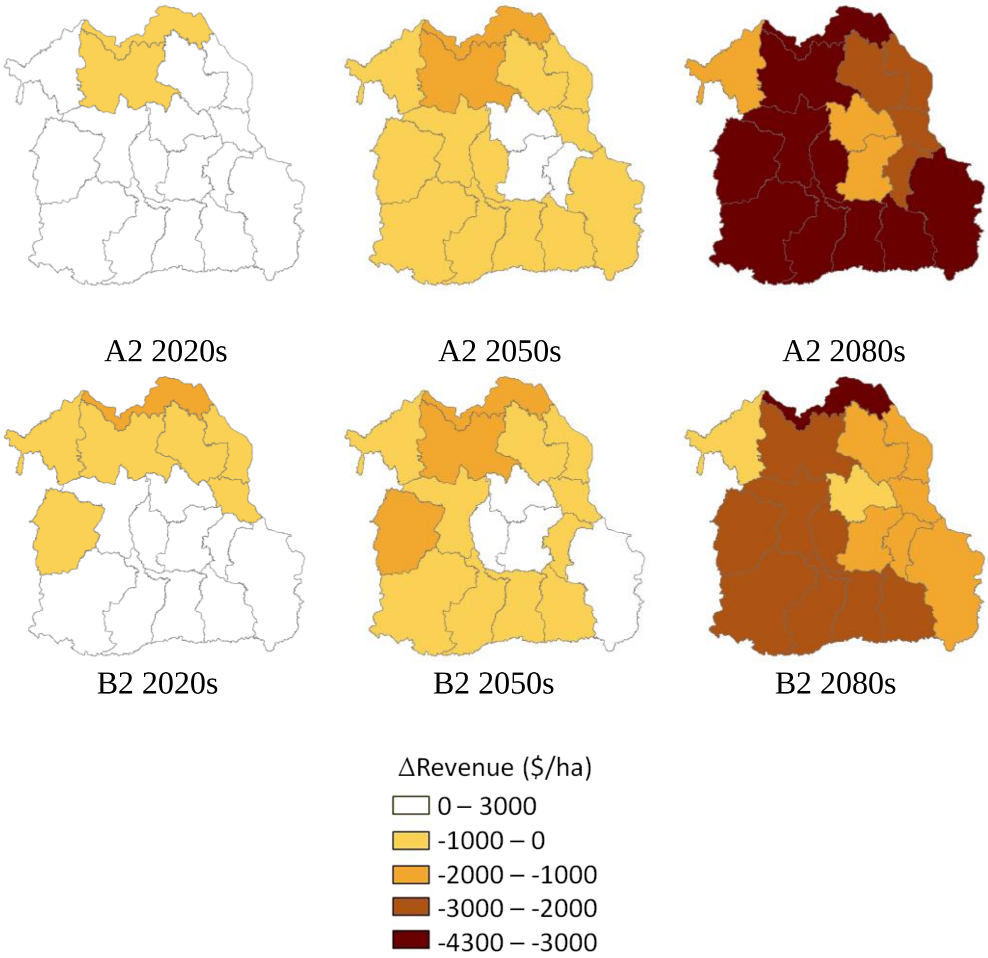


Figure 6.2 Changes in Farm-Level Net Revenue Corresponding to NE Thailand Projected Climate Change Scenarios SRES A2 and B2 for Three 30-Year Time Slices averaged over the 2020s, 2050s and 2080s ($/ha)

Source Author's compilations based upon farm-level net revenue in 2010 for provinces in NE Thailand minus with the projected farm-level net revenue calculation using coefficients from the year spatial panel fixed effects error model in Table 6.3

As can be seen from Figure 6.2, during the early of the 21st century (2020s), climate change is likely to advantageously affect agriculture in many provinces, particularly in the central and the lower parts of the region and climate change under SRES A2 scenario. The SRES A2 scenario is predicted to be more beneficial to agriculture in the provinces than the B2 scenario. Nong Khai and Udon Thani provinces are likely to lose out under the SRES A2 scenario while Nong Khai, Udon Thani, Chaiyaphum, Loei, Sakon Nakhon, Nakhon Phanom and Mukdahan provinces may be affected negatively under the SRES B2 scenario. During the middle of the 21st century (2050s), climate change is likely to begin to adversely affect agriculture in almost all the provinces in NE Thailand with the exception of the central part of the region. During the end of the 21st century (2080s), severe impacts are estimated to be borne by 10 provinces including Nong Khai, Udon Thani, Khon Kaen, Maha Sarakham, Chaiyaphum, Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket and Ubon Ratchathani under the SRES A2 scenario but only Nong Khai province under the SRES B2 scenario. It can be assumed that the two climate change scenarios A2 and B2 affect NE Thailand agriculture significantly different towards the end of the 21st century.

With regarding to the population change in the future, the study also projected the population density for each province in NE Thailand for 2010-2100 based on the medium fertility assumption of the world population prospects: the 2012 revision from United Nations, Department of Economic and Social Affairs, Population Division (DESA, 2013) and the Thai demographic structure from NESDB (2011). According to the medium fertility assumption, Thailand's population is projected to increase to 67.9 million people during 2010-2025 but decrease beyond this period until the end of the 21st century (DESA, 2013). The projected population density for each province in the region for the 2020s, 2050s and 2080s are the average of its projected population during 2010-2039, 2040-2069 and 2070-2099 divided by its provincial area, respectively. The results of projected population density for NE Thailand provinces are shown in the Appendix Table A62. According to Table 6.3 the preferred estimated climate response function: the year spatial panel fixed effects error model, the population density coefficient is negative; it can be implied that the growing population density reduces the farmers' income.

Additionally, the study projected farm-level net revenue by province corresponding to projected climate change scenarios and population density changes, holding other factors constant. These results are given in the Appendix Table A76. Furthermore, the study compared the projected average farm-level net revenue for NE Thailand corresponding to projected climate change scenarios for the region with the projected average regional farm-level net revenue corresponding to projected climate change scenarios and population density changes in Table 6.6. It is noted that NE Thailand average farm-level net revenue in year 2010 was about 1690 $/ha.

In the early decades of the 21st century (2020s), the maximum temperatures in summer, rainy and winter seasons under the SRES A2 scenario are likely to increase by 0.9°C, 0.6°C and 0.2°C, respectively, with reference to the baseline period. Under the SRES B2 scenario they are likely to increase by 1.67°C and 0.89°C in the summer and rainy seasons, respectively, but likely to decrease by 0.14°C in winter season with reference to the baseline period (Table 5.2). Relative to the baseline period, precipitation under the SRES A2 and B2 scenario is likely to decrease by 8.5% and 20.88%, respectively, in the summer season but likely to increase by 7.03% and 2.44%, respectively, in the rainy season, and expected to be absence in winter season (Table 5.2). These projected climate changes are likely to be beneficial to NE Thailand agriculture in the early decades of the century (2020s) which may increase the average farm-level net revenue by as much as approximately 2550 USD/ha (increase 51.2% with reference to farm-level net revenue in year 2010) under the A2 scenario and approximately 2030 USD/ha (increase 20.5% with reference to farm-level net revenue in year 2010) under B2 scenario (Table 6.6). Considering the impact of climate change together with the impact from the growing population density, the average farm-level net revenues for A2 and B2 scenarios are still increasing at slightly lower rates than the impact of climate change only (Table 6.6).

During the middle of the 21st century (2050s), the maximum temperatures in summer, rainy and winter seasons under the SRES A2 scenario are likely to increase by 1.7°C, 1.6°C and 1.3°C respectively with reference to the baseline period and under SRES B2 scenario by 1.8°C, 2.1°C and 0.7°C respectively with reference to the baseline period (Table 5.2). Precipitation in summer, rainy and winter seasons under the SRES A2 are likely to change by 2.3%, 13.1% and 0%, respectively, with reference to the baseline period while under SRES B2 scenario by -12.1%, 3.0% and 0%, respectively, with reference to the baseline period. The projected climate changes are likely to decrease NE Thailand farmer's income under SRES A2 and B2 by approximately 130 $/ha (-7.3%) and 250 $/ha (-14.5%), respectively, with reference to NE Thailand average farm-level net revenue in year 2010 of 1690 $/ha (Table 6.6). According to the

Appendix Table A62, the population density of NE Thailand is projected to decrease during the middle of the 21st century; therefore, the NE Thailand farmer's income affected by the aggregate impact of climate change and the population density change is projected to be slightly higher as compared with the climate change induced impact only (Table 6.6).

Table 6.6 Projected NE Thailand farm-level net revenue corresponding to projected climate change scenarios for the region only and corresponding to projected climate change scenarios and population density changes ($/ha)

Scenarios	Projected NR	
	Climate Change	Climate Change and Population Density Change
A2		
2020s	2549.9	2548.6
2050s	1563.0	1564.3
2080s	-1117.6	-1110.1
B2		
2020s	2032.0	2030.7
2050s	1442.7	1444.0
2080s	-106.2	-98.7

Source Author's calculation using coefficients from the year spatial panel fixed effects error model in Table 6.3

At the end of the 21st century (2080s), the maximum temperatures in summer, rainy and winter seasons under the SRES A2 scenario are likely to increase by 2.4°C, 3.6°C and 2.8°C, respectively, with reference to the baseline period and under the SRES B2 scenario by 2.7°C, 2.9°C and 1.7°C, respectively (Table 5.2 in chapter 5). The precipitation in summer, rainy and winter seasons under the SRES A2 is likely to change by 19.3%, 15.3% and 0%, respectively, with reference to the baseline period, while under the SRES B2 scenario by -2.7%, 7.4% and 0%, respectively (Table 5.2 in chapter 5). The projected average farm-level net revenues in NE Thailand are negatively affected by the climate change under the SRES A2 much more than the climate change under the SRES B2 (Table 6.6). The farmers in NE Thailand are predicted to experience losses as high as approximately 1120 $/ha (-166.3%) and 106 $/ha (-106.3%) under the SRES A2 and B2, respectively. The population density in NE Thailand is further projected to decrease by the end of the 21st century; hence, farmers in the region are predicted to experience losses less than the estimated losses impacted by the climate change only.

6.6 Discussion

Over the past decade, the use of the Ricardian approach has been expanding to estimate the economic impact of climate change on agriculture through the change of farmland value or the farm-level net revenue triggered by the changes in the climate variables along with other control variables such as soil quality and related socio-economic variables. According to previous Ricardian studies, both positive and negative economic impacts on agriculture are reported, as reviewed in section 6.2.

A recent study, using a hydro-agronomic-economic model for Mekong River basin and local adaptation in Thailand by DWR (2010) found both the positive and negative impacts of climate change on the NE Thailand agricultural production. The present study applies two climate change scenarios for NE Thailand based on the IPCC SRES A2 and B2 emissions scenarios developed by the SEA START RC and the DSSAT (Decision Support System for Agrotechnology Transfer) model to simulate crop response to climate changes. However, only four major crops are considered in this study including paddy rice, cassava, maize and sugarcane.

DWR (2010) projects NE Thailand future climate for the period 2040-2069 (referred to the 2050s) with reference to the baseline period of 1980-2009. The projections for the A2 and B2 scenarios indicate that maximum and minimum daily temperature would increase approximately 1.5°C over most of the region by the 2050s and annual precipitation would increase in the Kong-Isan and Chi basins with a little change in the Mun basin under the A2 scenario but would slightly change with a significant increase in variance in all basins by the 2050s under the B2 scenario (DWR, 2010). The results of the crop model DSSAT simulations show a significant increase in the yield of rain-fed rice but a decline in the yield of cassava and maize under both A2 and B2 scenarios while annual sugarcane and irrigated rice yields change very little (DWR, 2010). The net value of agricultural productions is projected to increase by about 17.5% under the A2 scenario, and by about 12.5% under the B2 scenario.

In this thesis, positive impacts of climate change on NE Thailand agriculture are projected in the early decades of the 21st century but negative impacts are projected to be borne by the middle and the end of the 21st century. The relationship between each climatic variable (i.e. precipitation and temperature in summer, rainy and winter seasons) and net revenue of farmers in NE Thailand is non-linear. The most of the square terms, in the preferred estimated climate response function: the year spatial fixed effects error model, are negative (Table 6.3). The negative quadratic coefficients of these climatic variables represent the beneficial effects of the slightly warmer temperature or the slightly higher precipitation on NE Thailand farmers' income during the early of the century but the adversely effects of the net revenue as these climatic variables are projected to increase too high during the middle and the end of the 21st century under both the A2 and B2 climate change scenarios.

There are both similarities and differences between the DWR (2010) study and this thesis. For example, both studies applied the same climate change scenarios based on SRES A2 and B2 developed by the SEA START RC for projecting NE Thailand future climates, but the DWR (2010) projects only for the middle of the 21st century while this thesis's projections cover the early, the middle and the end of the 21st century. The results of the climate projections during the 2050s, however, are different. The explanation may be the duration of time and the number of meteorological and hydro-meteorological stations used in the comparison with observed climate data.

The two studies have used the same 1980-2009 baseline period. DWR (2010) compared the PRECIS simulations of precipitation and temperature with observed data for the 1978-2007 periods at each of the 13 stations. However, this thesis compared simulated data with observed data of precipitation at each of the 173 hydro-meteorological station and temperature data at each of the 16 meteorological station for the 1980-2009 period. The DWR report (2010) claimed that there was variability in the quality of the simulations at different locations particularly the simulated precipitation data, which are needed as the input to a hydrological model, hence the DWR report (2010) carried out the PRECIS bias adjustment. It is argued that the quality of the precipitation and maximum temperature simulations are of sufficient quality for the assessment of economic impact of climate change on agriculture as the comparisons show that simulated maximum temperatures at 14 meteorological stations and simulated precipitation at 125 hydro-meteorological stations have the same mean as observed data for the 1980-2009 period. As such, this thesis did not apply the bias adjustment in the future climate data retrieved from the SEA START RC.

The bias adjustments led to a lower value of simulated climate data to be reported in the DWR report (2010) compared to the simulated climate data of this study. The different projection data between the two studies result to the different impact estimations. The DWR report (2010) projected the increases of the net value of agricultural productions by approximately 17.5% under the A2 scenario, and by approximately 12.5% under the B2 scenario during the 2050s. However, this thesis estimates the decreases of the NE Thailand farmer's income by approximately 130 $/ha (-7.3%) and 250 $/ha (-14.5%) during the 2050s under SRES A2 and B2, respectively, with reference to the NE Thailand average farm-level net revenue in year 2010 of 1690 $/ha (Table 6.6). In this thesis, increases of average farm-level net revenue are estimated to be 51.2% and 20.5% with reference to farm-level net revenue in year 2010 under A2 and B2 scenarios, respectively, during the early of the 21st century (Table 6.6). It can be assumed that a slight increase in temperature or precipitation will positively benefit farmers' income in NE Thailand.

In the study of economic effects of climate change on US agriculture by Adams et al. (1998), the sensitivity analysis of agricultural production to changes in temperature shows an interesting result. Nine climate change scenarios are estimated for a 2060 economy using 1990 as the baseline period. These nine scenarios include 1.5°C, 2.5°C and 5.0°C changes in temperature along with 0%, 7% and 15% changes in precipitation. The agricultural sector model ASM (Takayama and Judge, 1971) is used to calculate the maximum social welfare (the sum of consumer and producer surplus) for each climate scenario. The analysis reveals that the benefit estimates are likely to be maximised under a mild warming of about 1.5°C and fall thereafter at an increasing rate as temperatures continue to rise (Adams et al., 1998). Additional precipitation is likely to be strictly beneficial to net national benefit for the agricultural sector and the magnitude of benefits associated with higher precipitation is likely to be independent of temperature (Adams et al., 1998).

Consistent with Adams et al. (1998) study, this thesis also projects an increasing benefit of NE Thailand net revenue associated with the simulated maximum temperatures less than 1.5°C during the early of 21st century. Therefore, it is asserted that a lightly warmer temperature beneficially affects NE Thailand farm-level net revenue.

However, with regard to CO_2 fertilisation effects on yield of major crops i.e. rice, maize, cassava and sugar cane in NE Thailand, Kerdsuk et al. (2013) found that CO_2 fertilisation has a negative impact on cassava and maize yields about 2.7% and 9.2% during the early of the 21st century, respectively, and as high as 25.9% and 22.9% by the end of the 21st century, respectively (Table 3.1). It can be noted that there is a plausible loss in net revenue for cassava and maize in NE Thailand.

6.7 Conclusion

Spatial panel data analysis is a field of econometrics which is undergoing increased methodological progress (Millo and Piras, 2012). This thesis adopted the analysis of spatial panel data with rook-contiguity-based spatial weight to estimate the climate response function. In addition, the study assessed the impacts of various climate change scenarios as well as the future population density projection on NE Thailand agriculture based on the preferred estimated climate response function: the year spatial fixed effects error model.

The results indicated that the projected climate change scenarios for NE Thailand are likely to be beneficial to the regional agriculture in the early decades of the century (2020s) but likely to adversely affect the agriculture during the middle (2050s) and the end (2080s) of the 21st century. It can be seen that there are the significant differences between the two climate change scenarios SRES A2 and B2 effects on NE Thailand agriculture by the end of the 21st century as ten provinces, including Nong Khai, Udon Thani, Khon Kaen, Maha Sarakham, Chaiyaphum, Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket and Ubon Ratchathani are projected to experience the severe impacts of climate change under the A2 scenario while only Nong Khai province is estimated to experience the brunt of climate change impacts under the B2 scenario. With consideration of the demographical change in 2020s, 2050s and 2080s, the accumulated effects on NE Thailand agriculture are insignificantly different from the influence of climate change only. In the following chapter, the study will focus on the potential adaptation to climate change options.

Chapter 7

Adaptation Measures Recommendations

7.1 Introduction

Adaptation to climate change is a challenge faced by all Parties to the United Nations Framework Convention on Climate Change: UNFCCC (UNFCCC, 2013). As the impacts of climate change have begun to manifest themselves worldwide, adaptation to climate change therefore has attracted increasing attention (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2014; IPCC, 2014; Ogle et al., 2014). The impacts are expected to be particularly severe in the developing world and among marginalized communities because of limited adaptive capacity (Food and Agriculture Organization of the United Nations (FAO), 2007; Stage, 2010). Adaptation to climate change has become an important consideration in climate policy and research (Eastering et al., 2003; Pielke et al., 2007; Moser and Ekstrom, 2010; Berrang-Ford et al, 2011, Smith et al. 2011; Ford et al., 2013) since it is one of the major responses alongside mitigation for addressing climate change under the UNFCCC (UNFCCC, 2013).

The UNFCCC encourages the formulation and implementation of national or regional programmes containing measures to facilitate adequate adaptation to climate change (FAO, 2007). There has been substantial progress in the development of national adaptation strategies and plans as well as climate change adaptation (CCA) legislation (IPCC, 2014). Twenty-six members of the

Organisation for Economic Co-operation and Development (OECD) have developed or are currently developing strategic frameworks for national adaptation as of 2012 (Mullan et al., 2013). Fifty countries of Least Developed Countries (LDC) produced and submitted National Adaptation Programmes of Action (NAPAs) to UNFCCC as of 2013 (UNFCCC, undated c). Additionally, there has been an increasing body of academic literature and reports from multilateral development agencies, international organizations and NGOs for Climate Change Adaptation (CCA) around the world particularly in developing countries (IPCC, 2014).

There is also momentum for change at the community level. As remarked by the Executive Secretary of the UNFCCC (2014), climate change affects not just people but also species. The Golden Toad, for example, is extinct from the cloud forests of Monte Verde as a fungus spread encouraged by the drying out of the air and communities in Fiji have been forced as a result of flooding to leave their homes and move to higher ground (UNFCCC, 2014).

However, many countries are making changes (UNFCCC, 2014). Nepal, for instance, has initiated an organic composting project which process organic waste into compost to create value instead of waste; at the same time reducing methane emissions from landfills and providing long term jobs to the local community (Biocomp Nepal, undated). According to the recently released Global Trends in Renewable Energy Investment 2014 Report by UNEP (2014), in 2013, around $214 billion was invested in new renewables worldwide including a record 39 GW of solar power was installed around the world. But this momentum for change is not enough to realize carbon neutrality in the second half of the century; governments are urged to deliver their promise to scaling-up the support for adaptation nationally and in communities (UNFCCC, 2014).

To develop the national or regional adaptation strategies and plans, the key prerequisites for progress include (Gagnon-Lebrun and Agrawala, 2007)

- Improving national and regional climate change impact-related knowledge,
- Gathering information on climate change risks, and
- Promoting collaboration between researchers, policymakers and other stakeholders.

Following consideration of the economic impacts of climate change on agriculture in NE Thailand in Chapter 6, the objective of this chapter is to identify which sub-regional areas/units (provinces, districts or sub-districts, depending on the availability of the data) of NE Thailand are the most risk to climate change. In addition, this chapter further examine and develop adaptation measures and policies on climate change for the regional agricultural sector. A core component of this study is to collate, generate and disseminate relevant information that will allow policymakers to make informed choices on how they might respond to the way potential climate change may impact on agriculture.

The rest of this chapter is structured as follows; section 7.2 studies the adaptation to climate change impacts in Northeast Thailand. This study carried out the geographic CCR ‘hotspot’ analysis to explore where future climate stressors may have the greatest impact within NE Thailand and to examine how the existing planned adaptation for agriculture in NE Thailand can alleviate the risk from climate change impacts on agriculture in the region. Section 7.3 discusses the findings of this chapter and presents the recommended adaptation measures and policies climate change for NE Thailand agricultural sector. The last section provides concluding comments.

7.2 Adaptation to climate change impacts in Northeast Thailand

Thailand nowadays confronts a number of climate change impacts, such as flood, drought, landslide, rising sea level, biodiversity loss, and health risk (OAE, 2013). In the past decade, Thailand has formulated plans to response to climate change impacts, e.g. the Eleventh National Economic and Social Development Plan (NESDB, 2011a), Thailand Climate Change Master Plan (Draft) (ONEP, 2012) and Agriculture Strategic Plan on Climate Change (LDD, 2007).

In the Eleventh plan, climate change has been identified as one of the significant unpredictable global changes that Thailand has continued to face and may either pose threats or provide opportunities for the national development. The Eleventh plan highlights the need for strengthening of the agricultural sector to foster food and energy security and managing natural resources and the environment towards sustainability (NESDB, 2011a).

In the draft of the national climate change master plan, key adaptation strategies include building adaptive capacity of stakeholders, particularly small-scale agricultural and fishery communities; supporting an integrated water resources management (IWRM) ; encouraging sustainable agricultural productions and green land used planning; establishing natural disaster surveillance and early warning systems; raising public awareness; developing the climate change and biodiversity database, climate change and adaptation R&D networks, financial mechanism for adaptation; and supporting international cooperation (ONEP, 2012).

The agriculture strategic plan on climate change asserts that forecasting and early warning systems, crop improvement technologies, precision farming technologies, water resource management and modelling sector (including national data centre, national data transfer/management and integrated modelling using the weather forecasting technology) are the priority adaptation technology needs in agriculture (OAE, 2013).

Limskul et al. (2012) studied public expenditure and institutions on climate change in Thailand using 3-year database of national budget expenditure for 2009, 2010 and 2011 to map government's response to climate change. The study contributed an indicative classification of the entire national budget in terms of climate relevant expenditure, which allows an analysis of the linkages between emerging policy positions on climate change and government's implementation programmes funded through the national budget.

The study found that the climate budget was approximately THB 52000 million ($1040 million) per year or 2.7% of the government total budget (Limskul et al., 2012). There are 137 agencies in Thailand involved in the delivery of climate activity in government, however, only two agencies: the Royal Irrigation Department in Ministry of Agriculture and Cooperatives (MoAC) and Department of National Parks, Wildlife and Plant Conservation in Ministry of Natural Resources and Environment (MoNRE) accounting for approximately half of the allocated budget for climate related programmes in 2009-2011. Water distribution for all and increasing water storage and irrigated area programmes undertaken by MoAC are the most financially significant element, accounting for approximately 35% of the overall climate budget (Limskul et al., 2012).

Adaptation actions made up the largest component of the spending and accounted 68% of the national climate budget, while mitigation and relevant capacity building activities accounted for 21% and 9%, respectively (Limskul et al., 2012). Limskul et al. (2012) argued that the climate-change-policy theme has not been comprehensively addressed in the national budgetary process to date, nor through extra-budgetary funds. Hence, there is a need for climate-change-related public finance to be well planned within the national budgetary processes to cope with the iterative risk of damages by climate variability.

In terms of institutional arrangements to address climate change, the National Committee on Climate Change (NCCC) has been established, chaired by the Prime Minister, to direct the national climate change response (Limskul et al., 2012). Private sector institutional arrangements are already advancing through the representation of the Thai Chamber of Commerce and the role being played by Thailand Greenhouse Gas Management Organization (TGO). TGO is an implementing agency on GHGs emission reduction and particularly performing its role as the Designated National Authority for CDM (DNA-CDM) office in Thailand (TGO, undated).

The above climate-change-related plans and the findings of national climate public expenditure provide a useful focal point for adaptation assessment for agriculture in NE Thailand.

7.2.1 Integrated Water Resources Management Plans in NE Thailand

As stated by the IPCC (2014), the interaction between agriculture and water resources is considered to become increasingly significant as climate changes. Based on its significance in the national climate budget allocation and the priority adaptation technology need in agriculture, this thesis identified the IWRM as the key planned adaptation strategy for agriculture in NE Thailand. The IWRM Plans are focused on three river basins in NE Thailand: Kong (Isan) Basin (DWR, 2006a), Chi Basin (DWR, 2006b) and Mun Basin (DWR, 2005) were developed by Department of Water Resources. The IWRM plans are for 20 years. There are four strategies and measures for IWRM. They include:

- Water resources and water supply development strategy which involves procurement of water sources; improvement of water supply systems cover all villages in the region; development of irrigation system in potential areas; construction of community ponds to increase water storage; diversion additional water from both within and across the basins, which increase water budget in existing reservoirs in the late rainy season; and budget allocation for farmers who are affected by drought.

- Flood-damage mitigation strategy which involves establishing flood warning system; declaring flood risk areas; funding for the victims suffering from floods; and training local organisation to enhance their capacity in managing and solving flood problems effectively.

- Sustainability of water resources management strategy which involves establishing basin and sub-basin administrative organisations; developing water resource management plan at country and basin levels; participation among local people, water consumers and stakeholders whom affected by water resource management projects; and regularly monitoring and evaluating the integrated basin management plan, the environment and water quality.

- Water resources and water quality conservation strategy which involve raising awareness within public and local organisations for natural resource and environment conservation; public and community participation in preserving headwaters and wetlands; preserving, rehabilitating and increasing forest areas; improve water quality in natural water sources as well as expanding wastewater treatment plants; and establishing soil and water resources conservation areas.

There are 12780 planned projects divided into three groups including 2177 water resources development projects, 1241 flood-damage prevention and mitigation projects, and 9362 drought-damage prevention and mitigation projects (DWR, 2005; 2006a; 2006b). Table 7.1 presents a summary of the IWRM projects in NE Thailand. The water resources development projects consist of the large-, medium- and small-scale water resources development projects as well as the pumping irrigation projects. The flood-damage prevention and mitigation projects consist of the monkey cheek projects (the flood-control projects, which temporarily store excessive water during heavy rains in marginal agricultural areas and afterwards gradually drain it in order to alleviate the flood damage in fertile agricultural areas and urban areas), the construction of embankments, levees, dykes and drainage system projects. While the drought-damage prevention and mitigation projects consist of the construction and improvement of rural water supply projects, the construction of water conveyance systems and structure improvement projects, and groundwater resource development projects. The implementations under these IWRM plans are estimated to increase water storage and irrigation areas in the region by 259200 ha and 862470 ha, respectively (DWR, 2005; 2006a; 2006b).

Table 7.1 A summary of IWRM projects in NE Thailand

Province	Water Resources Development		Flood-Damage Prevention&Mitigation		Drought-Damage Prevention&Mitigation	
	Projects	Budgets (million $)	Projects	Budgets (million $)	Projects	Budgets (million $)
nm	200	212	157	56	1311	47
br	211	43	118	22	1188	47
sr	77	71	84	6	1338	78
ss	104	78	117	13	1760	73
ub	260	264	118	86	1255	58

Province	Water Resources Development		Flood-Damage Prevention&Mitigation		Drought-Damage Prevention&Mitigation	
	Projects	Budgets (million $)	Projects	Budgets (million $)	Projects	Budgets (million $)
ys	84	79	16	3	210	11
cp	172	324	47	7	106	34
kk	220	555	77	19	195	14
ud	133	129	64	28	217	19
lo	52	130	58	26	114	11
nk	40	92	74	44	200	21
mk	127	254	49	6	262	17
re	167	151	157	47	462	36
ks	112	131	41	6	218	15
sk	44	86	17	6	220	17
np	103	320	27	13	136	6
mh	71	153	20	46	170	12
Total	2177	3073	1241	434	9362	516

Source DWR (DWR, 2005; 2006a; 2006b)

7.2.2 Climate Change Risk (CCR) Mapping for NE Thailand

As part of the attempt to identify what adaptation options or strategies should be incorporated into NE Thailand development strategies, policymakers require adequate information on risks and vulnerabilities aiming to reduce risks and build adaptive capacity of the farmers in the region. This thesis uses a geographic CCR 'hotspot' analysis to explore where future climate stressors may have the greatest impact within NE Thailand. In order to undertake the CCR ‘hotspot’ analysis, this study applied the Weighted Sum Overlay in ArcGIS Spatial Analysis Tools (ESRI, 2010d) to calculate the potential risk to climate change score for each province in NE Thailand under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s. The Weighted Sum Overlay tool provides the ability to weight and combine multiple inputs to create an integrated analysis (ESRI, 2010e).

NE Thailand is not uniform. It is characterised by widely divergent climate systems, natural resources (soils, water), plant, farming and other land use systems, social systems (including population demographics) and economic strengths and weaknesses. Assessing the potential risk of this region to climate change must take into account these spatial differences. Davies et al. (2010) noted that arid environments are not necessarily at risk if socio-economic factors are strong, whereas climatically advantageous environments can be highly sensitive to population bloom burdens and destructive land management, leaving them at risk to climate change.

According to the findings in chapter 6, the projected climate change scenarios for NE Thailand are likely to be beneficial to the regional agriculture in the early decades of the century (2020s) but likely to adversely affect the agriculture during the middle (2050s) and the end (2080s) of the 21st century. Changes in temperatures and precipitation can be considered as the driving forces for the changes in NE Thailand farmers’ income. In addition, floods and droughts have adversely affected NE Thailand agriculture for a long time (Chula Unisearch and

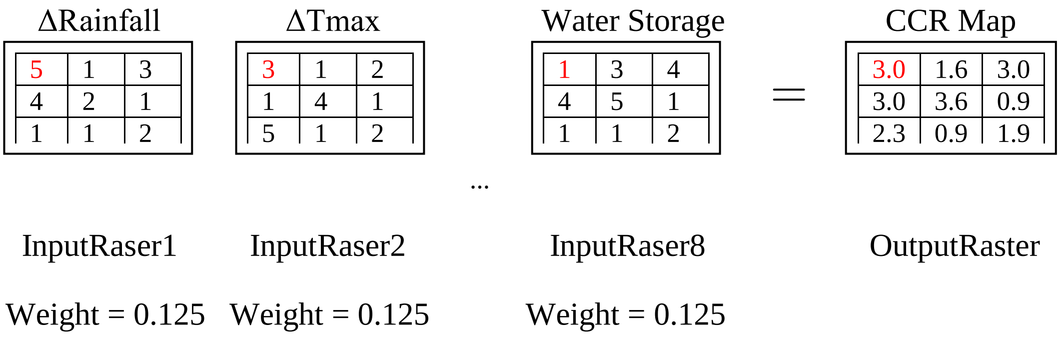
SEA START RC, 2012). However, the Thai government have taken the climate change impacts and damage from floods and droughts into account in formulating the integrated water resources management plans for three river basins in NE Thailand. These changes aim to alleviate the impacts and damage of climate change as well as building adaptive capacity for the farmers in the region. From these points of view, this thesis identified eight input criteria layers for the geographic CCR ‘hotspot’ analysis, which include:

- Three climate projected data for each province under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s, i.e. changes in maximum temperature (°C), changes in minimum temperature (°C) and changes in precipitation (%) with reference to the 1990s,

- Two triggered effects of the climatic stimuli, i.e. frequency of floods and cycle of droughts, and

- Three provincial socio-economic characteristics, i.e. projected changes in farm-level net revenue, irrigated areas and water storage areas.

As the input criteria layers have different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion have to be reclassified into a common preference scale. This study assigned 0 to 5, with 5 being the most risky score while 1 being the least risky score and 0 being no risk score. Table 7.2 presents the designated scores for each criterion in the geographic CCR ‘hotspot’ analysis for NE Thailand. The equal weightings, 0.125, are assigned for each indicator as insufficient information was available to judge the uncertainties of each estimate. The Weighted Sum works by multiplying the designated field values for each input raster by the specified weight, it then sum all input raster together to create an output raster (ESRI, 2010e). Figure 7.1 shows the calculation of the Weighted Sum Overlay in the NE Thailand geographic CCR ‘hotspot’ analysis.



(5*0.125) + (3*0.125) +...+ (1*0.125) = 3.0

Figure 7.1 Weighted Sum Overlay Calculation in the NE Thailand geographic CCR ‘hotspot’ analysis adapted from ESRI, 2010f

Table 7.2 The designated scores for the criteria in the NE Thailand geographic CCR ‘hotspot’ analysis

Difference in Maximum Temperature (°C)	Score
0.1 – 1.0	1
1.1 – 1.5	2
1.6 – 2.0	3
2.1 – 3.0	4
3.1 – 3.4	5
Difference in Minimum Temperature (°C)	Score
0.4 – 1.0	1
1.1 – 1.5	2
1.6 – 2.0	3
2.1 – 3.0	4
3.1 – 3.7	5
Difference in Precipitation (%)	Score
-6 – 0	1

1– 10	2
11 – 20	3
21 – 30	4
31 – 33	5
Frequency of Flood (times within 10 years)	Score
Area not affected by flood	0
≤ 3	1
4 – 7	3
8 – 10	5
Cycle of Drought (every X years)	Score
1 – 3	5
4 – 5	3
6 – 10	1
Area not affected by drought	0
20.1 – 25.0	1
15.1 – 20.0	2
10.1 – 15.0	3
5.1 – 10.0	4
≤ 5.0	5
Fraction of Area under Water Storage (%)	Score
3.1 – 3.7	1
2.1 – 3.0	2
1.1 – 2.0	3
0.6 – 1.0	4
≤ 0.5	5
Difference in Net Revenue ($/ha)	Score
0 – 3,000	0
-1,000 – 0	2
-2,000 – -1,000	3
-3,000 – -2,000	4
-4,300 – -3,000	5

Source Author's designation based upon the ranges of each criterion

Changes in maximum and minimum temperatures

In order to create three input raster of the climate projected for NE Thailand, this study used Raster Math in ArcGIS 3D Analysis Tools (ESRI, 2010g) to analyse changes in maximum temperature (°C), minimum temperature (°C) and precipitation (%) under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s with reference to the 1990s.

The estimated changes in maximum and minimum temperatures are calculated by adopting the minus tool (3D Analyst) to subtract the value of the baseline temperature maps from the value of the projected temperature maps on a cell-by-cell basis. Figure 7.2 presents the estimated changes in maximum temperature and figure 7.3 shows the estimated changes in minimum temperature with reference to the baseline period 1990s.

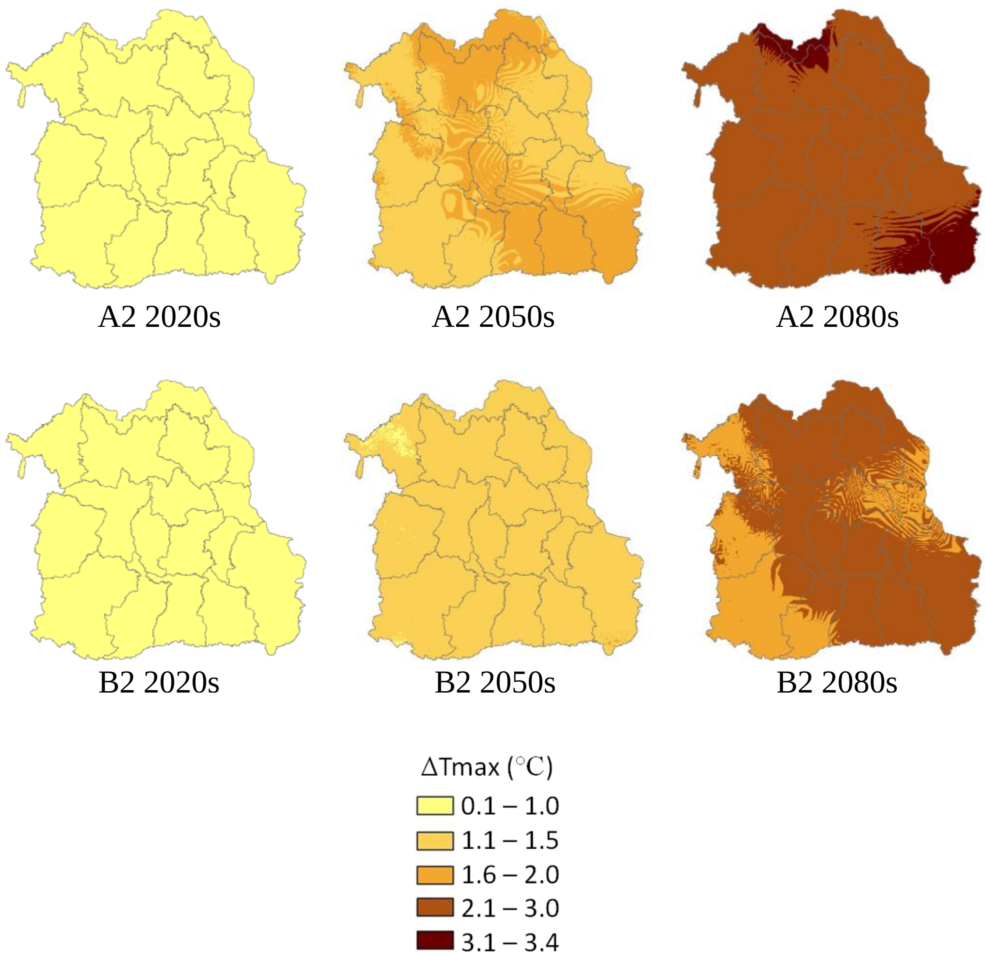


Figure 7.2 Changes in maximum temperature for NE Thailand under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s with reference to the 1990s calculated from SEA START RC data using minus tool (3D Analyst) in ArcGIS

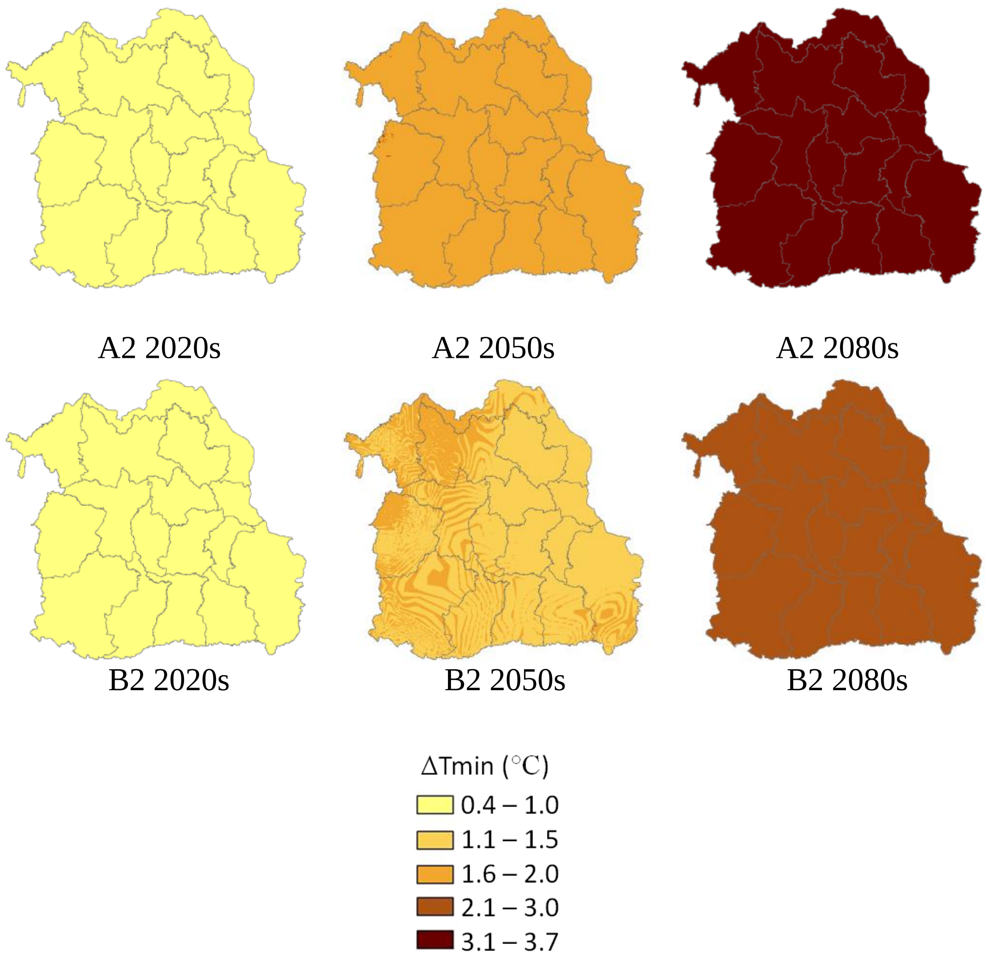


Figure 7.3 Changes in minimum temperature for NE Thailand under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s with reference to the 1990s calculated from SEA START RC data using minus tool (3D Analyst) in ArcGIS

Changes in precipitation

To estimate percentage changes in precipitation, this study adopted the minus tool (3D Analyst) to subtract the value of the baseline precipitation map from the value of the projected precipitation maps and then used the divide tool to divide the value of the subtracted maps with the value of the baseline precipitation map on a cell-by-cell basis. Finally, this study reclassified values in the divided maps by multiplying with 100 and the result maps are demonstrated in figure 7.4.

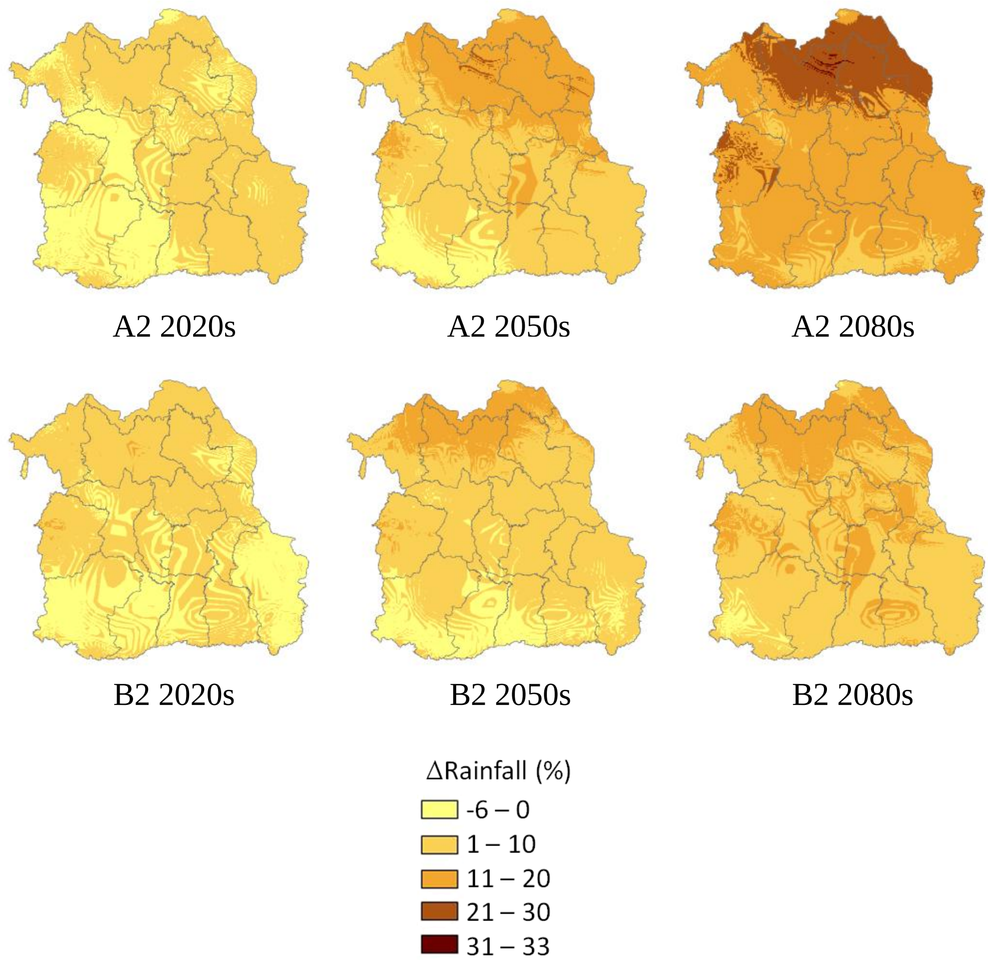


Figure 7.4 Percentage changes in precipitation for NE Thailand under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s with reference to the 1990s calculated from SEA START RC data using minus and divide tools (3D Analyst) in ArcGIS

Frequent and Severe Disasters: Floods and Droughts

The chronic impacts of climate change on NE Thailand agriculture are floods and droughts and there is a prediction of more frequent and severe floods in the future accordingly with an increasing precipitation projection under the IPCC SRES climate change scenarios (Chula Unisearch and SEA START RC, 2012). Maps of the risk of flood (times within 10 years) and the cycle of droughts (every X years) are developed as part of the Natural Disasters Warning System by the Office of Natural Calamity and Agricultural Risk Prevention, LDD, MoAC in Thailand. Figure 7.5 presents flood-prone areas which are identified into 3 levels by frequency of flooding within 10 years (LDD, undated a);

- High risk areas: areas are affected by floods 8-10 times within 10 years,
- Moderate risk areas: areas are affected by floods 4-7 times within 10 years,
- Low risk areas: areas are affected by floods up to 3 times within 10 years.

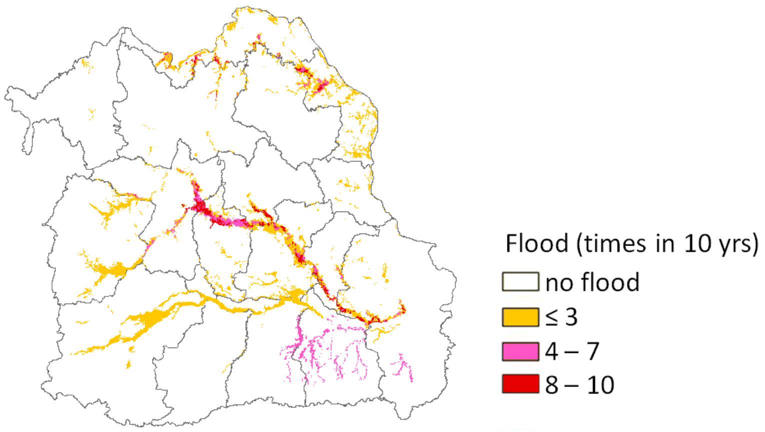


Figure 7.5 Flood-prone areas in NE Thailand (times within 10 years) from Office of Natural Calamity and Agricultural Risk Prevention, LDD, MoAC

The prolonged-drought areas are shown in figure 7.6, which are identified into 3 levels by cycle of droughts (every X years) (LDD, undated b);

- High risk areas: areas are affected by droughts in every 1-3 years per time.
- Moderate risk areas: areas are affected by droughts in every 4-5 years per time.
- Low risk areas: areas are affected by droughts in every 6-10 years per time.

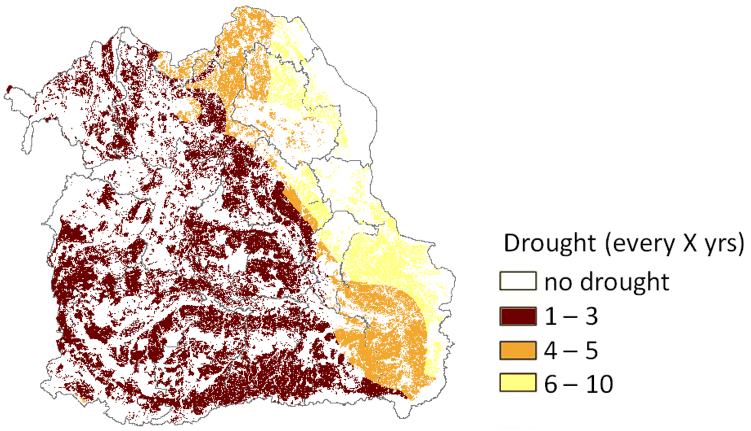


Figure 7.6 Prolonged-drought areas in NE Thailand (every X years) from Office of Natural Calamity and Agricultural Risk Prevention, LDD, MoAC

In terms of socio-economic factors, this study considered changes in farmer net revenue, irrigated and water storage areas as the climate change sensitive indicators for agriculture in NE Thailand.

Changes in farmer net revenue relative to 2010 net revenue

The maps of estimated change in farm-level net revenue under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s with reference to the 2010 net revenue developed in this thesis were presented in chapter 6, figure 6.2. In this chapter, the study employed those maps in this geographic CCR 'hotspot' analysis for NE Thailand. The Ricardian model outputs are aggregated as the input layers in the Weighted Sum Overlay analysis to determine provincial climate change sensitivity.

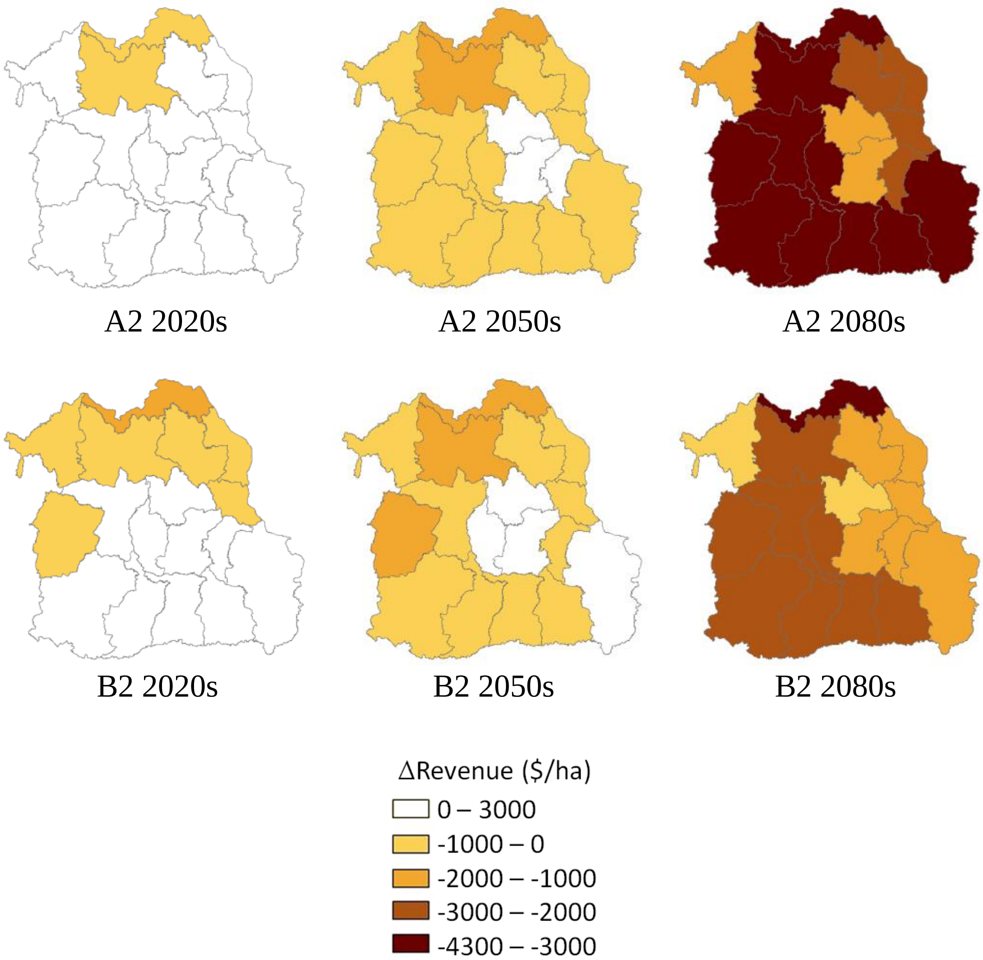


Figure 7.7 Changes in farm-level net revenue for NE Thailand corresponding to the projected maximum temperature and precipitation changes under the SRES A2 and B2 scenarios for the 2020s, 2050s and 2080s with reference to the 2010 farm-level net revenue (from chapter 6, figure 6.2). The maps are compiled applying the minus tool (3D Analyst) to subtract the value of the 2010 farm-level net revenue map from the value of the projected farm-level net revenue maps on a cell-by-cell basis

Fraction of Area under Irrigation (%)

The map of irrigation areas in NE Thailand was developed by Royal Irrigation Department, MoAC. Figure 7.8 shows irrigated land in NE Thailand. The fraction of area under irrigation is the percentage of irrigation areas in each province to its total land areas.

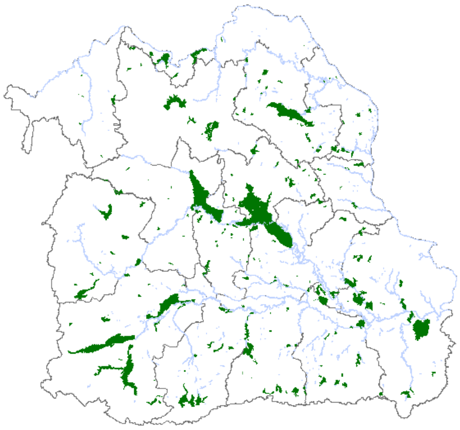


Figure 7.8 Irrigated Land in NE Thailand from Royal Irrigation Department

Fraction of Area under Water Storage (%)

The water storage or water body in NE Thailand map was generated by Department of Water Resources, MoNRE. Figure 7.9 depicts water storage in NE Thailand. Fraction of area under water storage (%) is the percentage of water storages in each province to its total land areas.

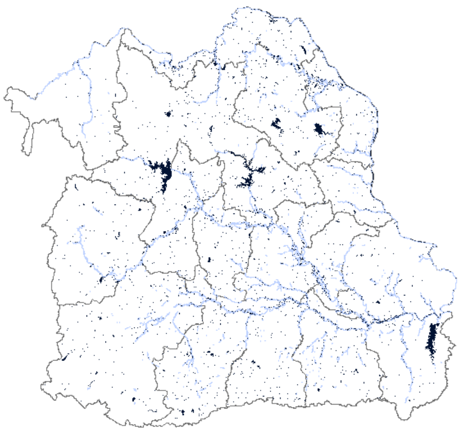


Figure 7.9 Water Storages in NE Thailand from DWR

The New Input Criteria for the Geographic CCR 'Hotspot' Analysis in the case of "With" Planned Adaptation

As the water storage and irrigation areas are estimated to increase by 259200 ha and 862470 ha, respectively, if the IWRM plans are fully implemented in NE Thailand, therefore, the additional water storage and irrigation areas can be considered as the input criteria in the geographic CCR 'hotspot' analysis in the case of "with" planned adaptation. This study compared weighted sum scores of the potential risk to climate change considering "without" and "with" planned adaptation. This is the attempt to examine how the existing planned adaptation for agriculture in NE Thailand can alleviate the risk from climate change impacts on agriculture in the region. It can be seen as the evaluation/trade off stage in the iterative risk management if the IWRM plans are fully implemented in NE Thailand. The analysis presented in this thesis is expected to provide policymakers with adequate information on CCR management for agriculture in NE Thailand.

According to the spatial panel fixed effects error model developed for this thesis in Table 6.3 (in chapter 6), irrigated land is positively associated with farm-level net revenue. Therefore, the NE Thailand farm-level net revenue is expected to increase due to the additional irrigation areas if the IWRM plans are fully implemented. In addition, this thesis took the projected population density for each NE Thailand province into account (see details in the Appendix Table A62). In the projection of NE Thailand farm-level net revenue in the case of “with” planned adaptation, this study calculated the projected farm-level net revenue corresponding to the projected maximum temperature and precipitation changes under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s; population density changes averaged over the 2020s, 2050s and 2080s; and the additional irrigation area changes if the IWRM plans are fully implemented. The calculations were applied to the coefficients from the year spatial panel fixed effects error model in Table 6.3 (in chapter 6). To generate the maps, this study adopted the minus tool (3D Analyst) to subtract the value of the 2010 farm-level net revenue map from the value of the projected farm-level net revenue maps on a cell-by-cell basis. Figure 7.10 presents the projection of NE Thailand farm-level net revenue in the case of “with” planned adaptation.

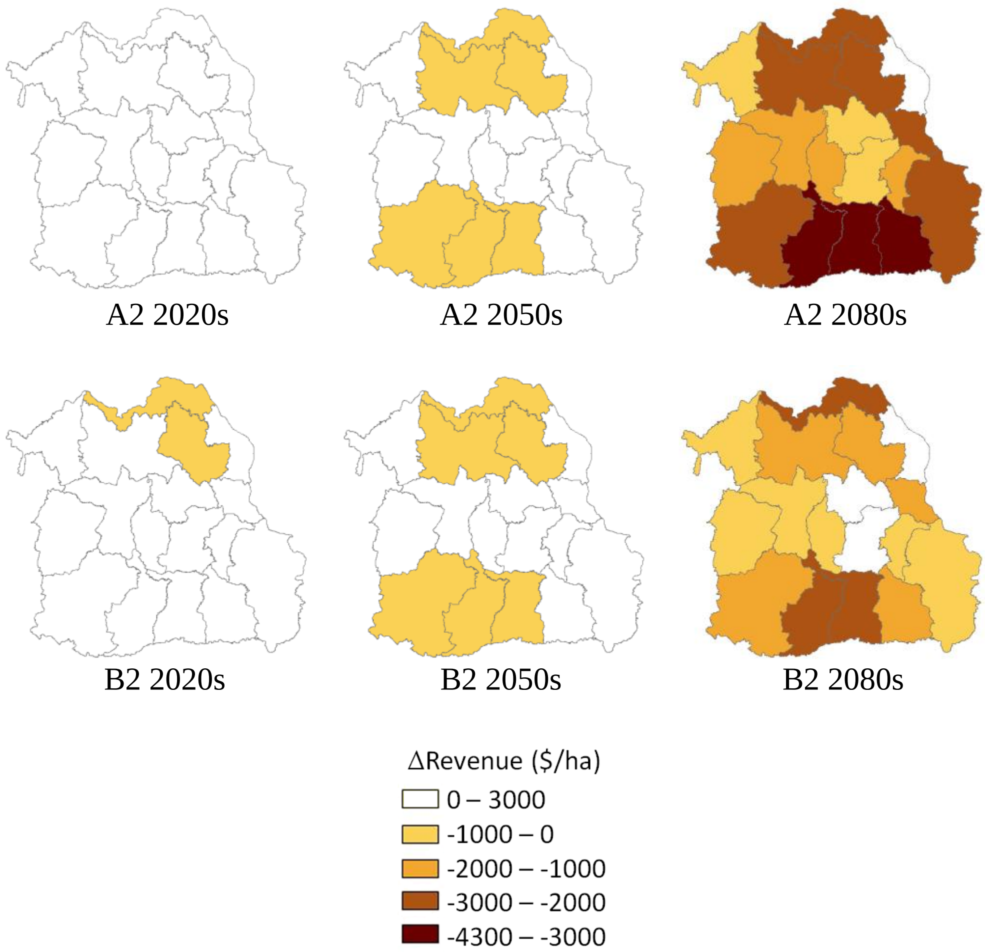


Figure 7.10 Changes in farm-level net revenue for NE Thailand corresponding to the projected maximum temperature and precipitation changes, population density changes and additional irrigation areas if the IWRM plans are fully implemented, calculated using coefficients from the year spatial panel fixed effects error model in Table 6.3 (in chapter 6) under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s with reference to the 2010 farm-level net revenue

With regard to the risk from floods and droughts in NE Thailand, this study believed that the frequencies of flood and drought could be reduced as the implementation of the planned adaptation. Therefore, in the geographic CCR 'hotspot' analysis in the case of "with" planned adaptation, this study adopted the new input criteria layers of flood-prone areas and prolong-drought areas, as shown in Figure 7.11 and 7.12, respectively.

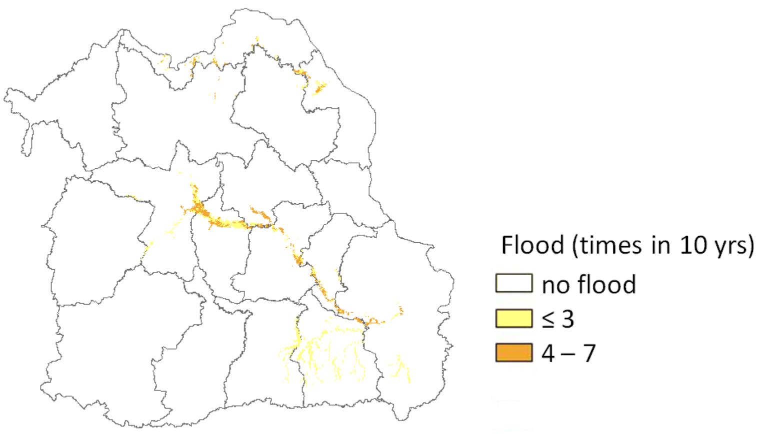


Figure 7.11 Expected flood-prone areas in NE Thailand (times within 10 years) as the IWRM plans are fully implemented, adapted from Office of Natural Calamity and Agricultural Risk Prevention, LDD, MoAC

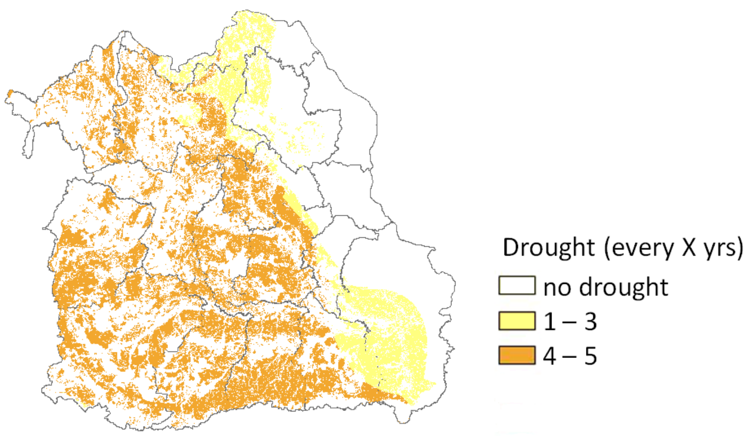


Figure 7.12 Expected prolonged-drought areas in NE Thailand (every X years) as the IWRM plans are fully implemented, adapted from Office of Natural Calamity and Agricultural Risk Prevention, LDD, MoAC

In order to calculate the potential risk to climate change score for each province in NE Thailand using the Weighted Sum Overlay tool, there is a need for this study to carry out the reclassification of the value in each cell for each criterion into a designated scale as shown in table 7.2. This study applied the Reclassify tool in ArcGIS Spatial Analysis Tools (ESRI, 2010h) to reclassify the input criteria layers into the input criteria score layers.

In the geographic CCR 'hotspot' analysis in the case of "without" planned adaptation, this study combined eight input criteria score layers including three of the projected climate changes under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s, 2080s, i.e. the change in maximum temperature, minimum temperature and precipitation, as well as the flood-prone area score layer, the prolonged-drought area score layer, the projected change in farm-level net revenue score layer (under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s, 2080s), the irrigated land score layer and the water storage score layer into the Weighted Sum Overlay tool given the equal weight, 0.125, for each criterion.

In the geographic CCR 'hotspot' analysis in the case of "with" planned adaptation, this study followed the same process as it did in the case of "without" planned adaptation by combining eight input criteria score layers into the Weighted Sum Overlay tool given the equal weight, 0.125, for each criterion. This study employed the same score layers of three projected climate data under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s, 2080s including the change in maximum temperature, minimum temperature and precipitation. However, this study applied the five new criteria score layers including;

- The additional irrigated land score layer,
- The additional water storage score layer,
- The projected change in farm-level net revenue score layer (under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s, 2080s) corresponding to the projected maximum temperature and precipitation, the population density changes and the additional irrigation areas as the implementation of the planned adaptation,
- The flood-prone area score layer, and
- The prolonged-drought area score layer.

Table 7.3 The ranges of potential risk score for NE Thailand in the case of "without" and "with" planned adaptation under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s, calculated using the Weighted Sum Overlay tool in ArcGIS.

Climate Change Scenarios	"without" planned adaptation	"with" planned adaptation
A2		
2020s	1.25-3.00	1.00-2.25
2050s	1.38-3.38	1.00-2.88
2080s	2.25-4.25	1.63-3.75
B2		
2020s	1.25-3.00	1.00-2.38
2050s	1.50-3.5	1.12-3.0
2080s	2.00-4.00	1.50-3.50

Figure 7.13 shows the potential risk to climate change score for NE Thailand in the case of "without" planned adaptation, calculated using the Weighted Sum Overlay tool in ArcGIS and figure 7.14 presents the potential risk to climate change score for NE Thailand in the case of "with" planned adaptation, calculated using the Weighted Sum Overlay tool in ArcGIS.

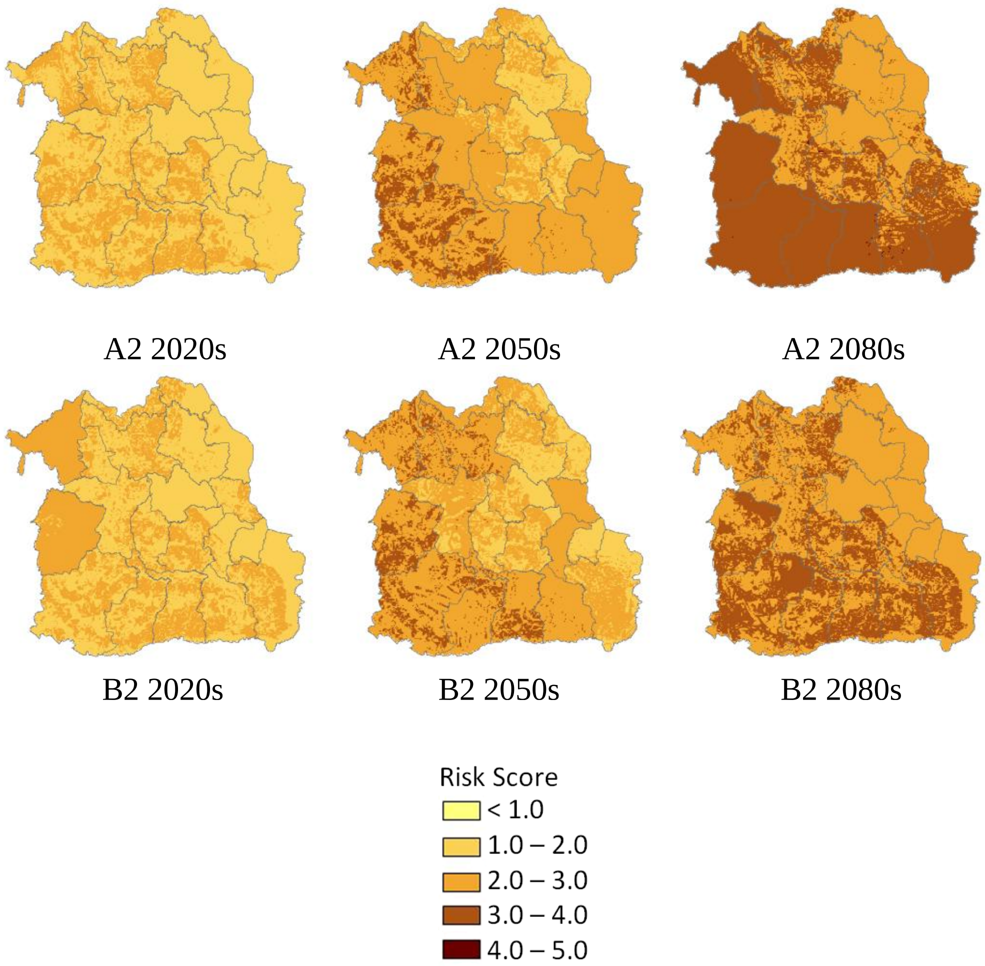


Figure 7.13 Potential risk to climate change score for NE Thailand in the case of "without" planned adaptation under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s, 2080s, combined eight input criteria including the projected change in maximum temperature; projected change in minimum temperature; projected percentage change in precipitation; flood-prone area; prolonged-drought area; projected change in farm-level net revenue corresponding to projected climate change; irrigation areas and water storage areas given the equal weight of 0.125 for each criterion using the Weighted Sum Overlay tool in ArcGIS

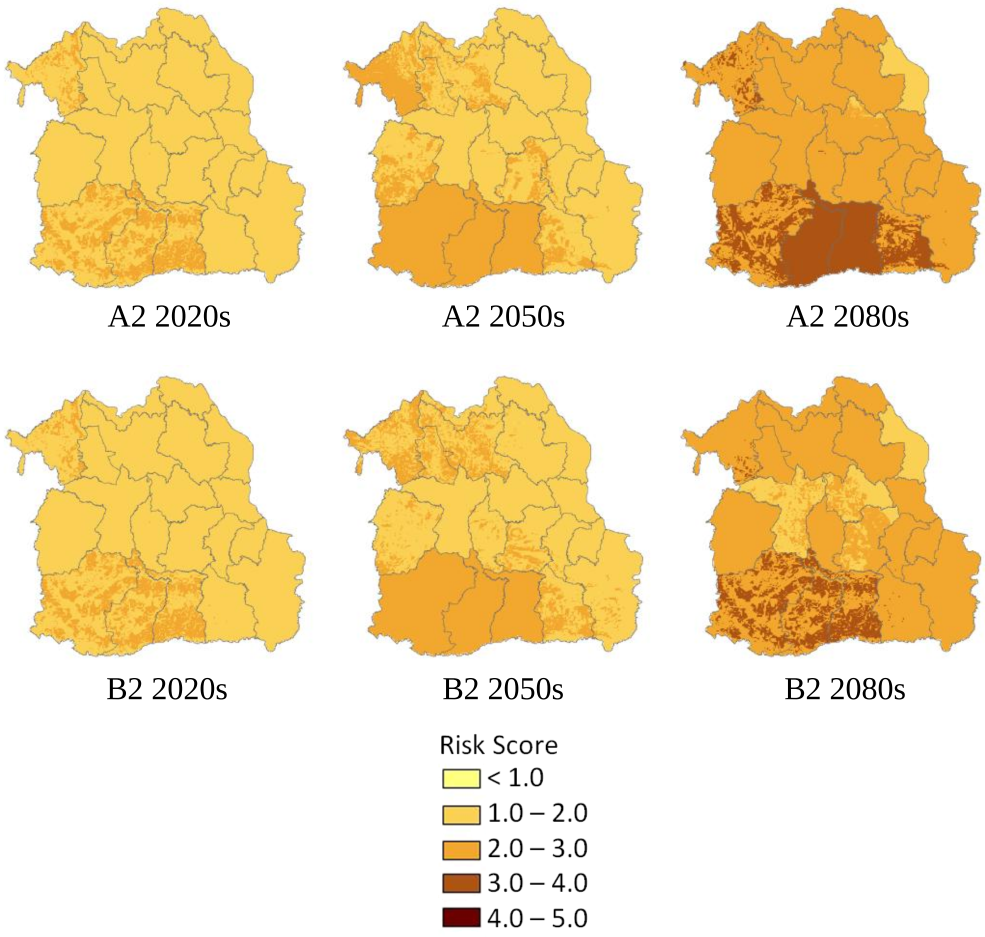


Figure 7.14 Potential risk to climate change score for NE Thailand in the case of "with" planned adaptation (as the IWRM plans are fully implemented), combined eight input criteria including the projected change in maximum temperature; projected change in minimum temperature; projected percentage change in precipitation; additional irrigation areas; additional water storage areas; projected change in farm-level net revenue corresponding to the projected maximum temperature and precipitation changes, population density changes and additional irrigation areas; reduced-frequency flood-prone area; and reduced-frequency prolonged-drought area, using the Weighted Sum Overlay tool in ArcGIS, estimated under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s

7.4 Discussion

As mentioned in chapter 1, one of the objectives of this thesis is to identify which sub-regional areas/units (provinces, districts or sub-districts, depending on the availability of the data) of NE Thailand are the most risk to climate change. To achieve this objective, this chapter carried out a geographic CCR ‘hotspot’ analysis to explore the areas in NE Thailand that future climate stressors may have the greatest impact. In addition, this study compared the weighted sum scores of the potential risk to climate change considering “without” and “with” planned adaptation as are presented in figure 7.13 and 7.14, respectively, to evaluate how the IWRM plans, as in this study is identified as the key planned adaptation for agriculture in NE Thailand, can alleviate the risk from climate change impacts.

The final summary hotspot layers in the geographic CCR ‘hotspot’ analysis (figure 7.13 and 7.14) indicated that all provinces in NE Thailand are at risk of climate change. The dark-coloured areas indicate the hotspots where farmers are most likely to be need of help adapting to climate stressors, while the brighter areas indicate the lower sensitivity to climate change. Table 7.3 presents the ranges of potential risk score for NE Thailand in the case of “without” and “with” planned adaptation under the SRES A2 and B2 climate change scenarios for the 2020s, 2050s and 2080s.

During the early of the 21st century (2020s), the ranges of potential risk score in the case of “without” planned adaptation for both the SRES A2 and B2 climate change scenarios are 1.25-3.00 (Table 7.3). It can be seen from figure 7.13 that the provinces in the western and central part of NE Thailand are more likely to be at risk than the provinces in the eastern part which border the Mekong River. Under the SRES B2 scenario almost all areas in Loei and Chaiyaphum provinces are likely to be at risk of climate change. The prolonged-drought criterion layer (figure 7.6) indicates that many areas in these two provinces are affected by droughts in every 1-3 years. The fraction of area under irrigation and water storage areas criteria layers (figure 7.8 and 7.9, respectively) indicate that Loei and Chaiyaphum provinces are at high risk as they have the smallest fractions of these two factors. In addition, the change in farm-level net revenue criterion layer (figure 7.7) indicates that these two provinces are projected to experience losses during the early of the 21st century under the SRES B2 scenario. Combining all these factors' almost all of Loei and Chaiyaphum provinces are sensitive to climate change under the SRES B2 scenario.

During the early 21st century (2020s), in the case of "with" planned adaptation for the SRES A2 and B2 climate change scenarios, the potential risk score range from 1.00-2.25 and 1.00-2.38, respectively (Table 7.3). It can be seen from the figure 7.14 that there are only four provinces, Loei, Nakhon Ratchasima, Buri Ram and Surin provinces are at the higher risk. Under the SRES B2 scenario in figure 7.14, however, the risk associated with climate change in the Chaiyaphum province is reduced drastically under the implementation of the IWRM plans. According to the IWRM plans (DWR, 2005; 2006a; 2006b), there are large-scale water resources development projects in Chaiyaphum province hence the fraction of irrigation areas is estimate to increase from 4.64% in 2010 to 9.13%

and the fraction of water storage areas is estimate to increase from 0.65% in 2010 to 2.08% if the IWRM plans are fully implemented.

During the middle of the 21st century (2050s) and “without” planned adaptation almost every province in NE Thailand is expected to be at higher risk to climate change compared with the 2020s for both the SRES A2 and B2 climate change scenarios. In the B2 scenario, only Am Nat Charoen province is at the same risk as the 2020s.

During the middle of the 21st century (2050s) and “with” planned adaptation, a smaller number of provinces are expected to be at the higher risk to climate change compared with the 2020s for both the SRES A2 and B2 climate change scenarios. Under the SRES B2 scenario all areas in Nakhon Ratchasima, Buri Ram and Surin provinces are projected to be at the higher risk as climate change. The potential risk stems from the high risk to prolonged-drought, the small fraction of area under irrigation and water storage areas and the projected losses in farm-level net revenue.

By the end of the 21st century (2080s) and “without” planned adaptation, the results from the geographic CCR ‘hotspot’ analysis under the SRES A2 climate change scenario indicate that 62 sub-districts in 22 districts of 8 provinces across NE Thailand (Figure 7.15) are at risk of climate change as the potential risk scores of these sub-districts are higher than 4. However, no province is at such a high risk if the IWRM projects are fully implemented in NE Thailand.

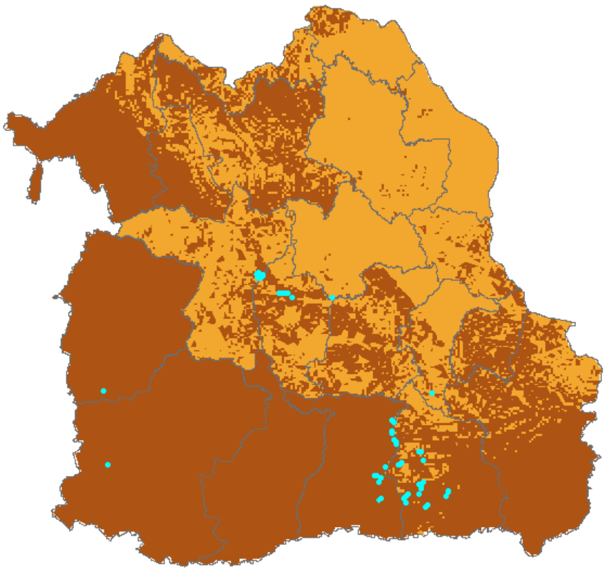


Figure 7.15 The “hotspot” sub-districts in NE Thailand in the case of “without” planned adaptation under the SRES A2 climate change scenario for the 2080s, indicated by the potential risk score more than 4, calculated using the Weighted Sum Overlay tool in ArcGIS (2.0 x sizes of A2 2080s in Figure 7.13)

Table 7.4 Climate change hotspot sub-districts in NE Thailand and dominant risks.

Provinces	Sub-districts	Dominant risks
Kalasin	Lam Chi	Flood-prone
Khon Kaen	Phra Lap and Don Han	Flood-prone, prolonged-drought, changes in farm-level net revenue
Chaiyaphum	Ban Phet and Ban Chan	Irrigated land, water storage, prolonged-drought, changes in farm-level net revenue
Nakhon Ratchasima	Si Khiu	Irrigated land, water storage, prolong-drought, changes in farm-level net revenue

Provinces	Sub-districts	Dominant risks
Yasothon	Maeng and Pea Hi	Flood-prone
Maha Sarakham	Kwao Rai, Hua Kwang, Kaeng Kae, Tha Song Kon, Phon Ngam, Kwao Yai, Tha Tum, Nong Bua, Hae Tai and Leang Tai	Flood-prone, changes in farm-level net revenue
Si Sa Ket	Muang Chan, Huai Tap Tan, Thung Sawang, Pi Mai Nua, Tum, Phon Yang, Bu Sung, Samrong Prasat, Phak Mai, Kuai Kwang, Huai Nua, Phai Beang, Kra Wan, Huai Samran, Prasat, Khok Tan, Ta Kian, Ta Kon, Huai Tai, La Lom, Prea Yai, Samrong Plan, Prasat, Ku, Sano, Phai, Dong Kham Met, Pho Kra Sang, Kanthara Rom and Chai Di	Irrigated land, prolonged-drought, changes in farm-level net revenue
Surin	Pra Du, Kra Oom, Phak Mai, Kut Wai, Kho Kaeo, Narong, Ta Kong, Khon Teak, Traew, Sang Ka, Kham Pong, Nong Luang, Berd and Sano	Irrigated land, water storage, prolonged-drought, changes in farm-level net revenue

Adaptation Measures and Policies Climate Change for the NE Thailand Agricultural Sector

It is clear that the implementation of the IWRM plans would alleviate the risk from climate change in the NE Thailand agricultural sector. Delays in implementing the IWRM plans may leave NE Thailand agriculture at risk from climate change. Therefore, this study recommends that the related development agencies, e.g. the Royal Irrigation Department, the Department of Water Resources, Department of Public Works and Planning, MoAC, the twenty NE

Thailand provincial administration organisations and the local administration organisations, expedite the implementation of the IWRM plans.

This thesis also found that if the IWRM plans are fully implemented, NE Thailand agriculture is still at risk to climate change. As stated by the IPCC (2014) no single method suits all contexts. Therefore, it is necessary for the policy-makers to consider more adaptation strategies and measures.

This study recommends the following adaptation measures and policies climate change for NE Thailand agricultural sector:

- Expedite the implementation of the IWRM plans for Kong (Isan), Chi and Mun basin in order to increase the irrigation and water storage areas and reduce the damages from floods and droughts as well as building an adaptive capacity for farmers in NE Thailand,

- Encourage the government to develop a crop insurance scheme and persuade private companies to get involved with this scheme or create their new crop insurance products in order to help the farmers, particularly in the hotspot sub-districts identified in this thesis, to deal with increased climatic variability and change,

- Increase farmers' income for example by promoting the diversification of agricultural production as a means to increase farmers' sources of income as well as income from off-farm activities,

- Improving agricultural productivity both in irrigated and rain-fed areas, and improving soil fertility and solving problem of saline soil throughout the region. This may be done for example by implementing the zaï technique of the West African Sahel traditional integrated soil and water management (Fatondji et al, 2009) to improve soil fertility in NE Thailand,

- Increase the efficiency of water utilisation, and promoting the less-water-intensive crop cultivations such as vegetables, flowers, grapes and high-quality-seed grass,

- Encourage the utilisation of the indigenous knowledge, which is suitable with the socio-geographical conditions of the community, i.e. changing varieties and planting times. These incremental adaptation actions are commonly found within different agricultural systems (e.g. Monzon et. al., 2007; Meza et al., 2008; Orlandini et al., 2009; Tingem and Rivington, 2009; Passioura and Angus, 2010; Walter et al., 2010 and Cho et al., 2012),

- Reinforce the community to conserve and restore natural resources and the environment including forests, water resources and soil as well as preserving and developing biodiversity and efficiency utilising natural resources following effective management under a sustainable development approach

- Supporting climate change-related R&D, e.g. research on new climate change scenarios RCPs (IPCC, 2014), climate change impact assessment, climate change adaptation, climate change risk management, new varieties of crops suitable with the changing climate.

7.5 Conclusion

Climate change is a slow and complex phenomenon. In order to aptly detect the direction, magnitude and the change in future climate pattern, long-term climate projections are needed (Chinvanno, 2009). To assess the impact of climate change in agriculture as well as supporting long-term planning, long-term climate scenarios are required.

This study achieved this requirement by developing long-term climate change scenarios for NE Thailand under the SRES A2 and B2 climate change scenarios for 2020s, 2050s, and 2080s based upon data from the SEA START RC. These scenarios were used to assess the economic impacts of climate change on the regional agricultural sector through the projected changes in farm-level net revenue as climate change (in chapter 6) as well as to identify which sub-districts of NE Thailand are the most risk to climate change and to examine the adaptation measures through the geographic CCR 'hotspot' analysis (in this chapter).

The findings from this research indicated that during the early part of the 21st century (2020s), farmers in many provinces (e.g. Khon Kaen, Maha Sarakham, Kalasin, Roi Et, Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket, Ubon Ratchatani and Yasothon provinces) are projected to be positively affected by climate change while farmers in only two provinces (Udon Thani and Nong Khai provinces) are projected to be adversely affected by the projected increases of maximum temperature and precipitation under both the SRES A2 and B2 scenarios (figure 7.7). The geographic CCR 'hotspot' analysis confirms the lower level of risk to climate change for agriculture in NE Thailand (the ranges of potential risk are 1.25-3.00) for both the SRES A2 and B2 climate change scenarios (Table 7.3).

In contrast, during the middle of the 21st century (2050s), farmers in many provinces (e.g. Loei, Udon Thani, Nong Khai, Chaiyaphum, Khon Kaen, Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket, Sakhon Nakhon, Nakhon Panom and Mukdahan provinces) are forecasted to experience losses while farmers in only two provinces (Kalasin and Roi Et provinces) are projected to benefit from climate change under both the SRES A2 and B2 scenarios (figure 7.7). The geographic CCR 'hotspot' analysis also supported the finding from the impact assessment with the higher ranges of potential risk for both the SRES A2 and B2 climate change scenarios (Table 7.3).

By the end of the 21st century (2080s), this thesis found that farmers in all provinces are expected to be adversely affected by the projected much higher increases of maximum temperature and precipitation under both the SRES A2 and B2 scenarios (figure 7.6). The findings from the geographic CCR 'hotspot' analysis under the SRES A2 climate change scenario indicated the hotspots in 62 sub-districts in 22 districts within 8 provinces across NE Thailand, which are at the most risk to climate change as their potential risk scores are higher than 4 (Figure 7.14).

In the comparison between the weighted sum scores of the potential risk to climate change considering "without" and "with" planned adaptation, the findings demonstrated the importance of a full implementation of the key planned adaptation, the IWRM, that would alleviate the risk to climate change in the NE Thailand agricultural sector.

Finally, the recommended adaptation measures and policies for climate change in NE Thailand agricultural sector include: expediting the implementation of the IWRM plans; encouraging the development of a crop insurance scheme; increasing farmers' income by promoting the agricultural diversification as well as income from off-farm activities; improving the agricultural productivity both in irrigated and rain-fed areas and improving soil fertility and solving problem of saline soil throughout the region; increasing the efficiency of water utilisation, and promoting less-water-intensive crop cultivations; encouraging the utilisation of the indigenous knowledge; conserving and restoring natural resources and environment; and supporting the climate change-related R&D.

Chapter 8

Conclusions

The main aim of this thesis is to assess the economic impact of climate change and climatic variability on agriculture in NE Thailand with particular focus to examine how the projected changes in temperature and precipitation may affect the NE Thailand farm-level net revenue as well as to develop the adaptation measures and policies climate change for the agriculture sector. The findings of this study contribute to existing knowledge on economic impacts of climate change and adaptation to climate change by providing policymakers with the necessary scientific information for future policy decisions in NE Thailand. Section 8.1 of this chapter summarises the research that had been accomplished as part of this thesis. Section 8.2 describes a number of limitations associated with this thesis. Section 8.3 recommends future research possibilities.

8.1 Research Summary

Climate change is a slow and complex phenomenon. Therefore, decision-making in climate change context involves long time scales and that have led uncertainties associated with many risks. A core component of this study is to collate, generate and disseminate relevant information on the impacts of climate change and adaptation to climate change for NE Thailand agricultural sector. Firstly, chapter 2 reviewed current knowledge on climate change and related issues, such as economic impact of climate change, the value and the relative important of the ecosystem services, and the linkage between climate change and agriculture. This chapter provided the fundamental background on climate change in the context of agriculture for the remainder of this thesis.

Chapter 3 provided an overview of the development background for NE Thailand and the recent knowledge about climate change in this region. In the Eleventh plan, climate change has been identified as one of the significant unpredictable global changes that Thailand has continued to face and may either pose threats or provide opportunities for the national development. The Eleventh plan highlights the need for strengthening of the agricultural sector. This chapter provided the policy context for this study.

Chapter 4 discussed the methods and data acquisitions used throughout this study. At the starting point of the analysis, it is important for this study to gain insight into the patterns of variability of current and projected climate in NE Thailand as this information is required as input data in the subsequent analysis of economic impact of climate change on agriculture in NE Thailand and assess the adaptation to climate change for NE Thailand agricultural sector. Therefore, the chapter began by providing an overview of the available climate change scenarios for NE Thailand and discussed the advantage of the utilisation of the climate change scenarios developed by the SEA START RC which were selected for this research. In chapter 4, this study also outlined two main methods to measure the economic impacts of climate change on agriculture including the production function approach and the Ricardian approach and debated the advantages and disadvantages of each of these methods. The classic Ricardian model specification was discussed and it provided the information of input data required for this study. In addition, the iterative risk management approach was discussed in the adaptation and managing risks in agriculture section as a tool for assess adaptation. The last section described the components of the comprehensive province-level dataset utilised for the purpose of the analysis in this research.

In chapter 5, this thesis carried out the climate change projection for NE Thailand. Two sets of NE Thailand climate data were studied including the 1984-2010 observed climate data collected by TMD and the 1980-2099 projected climate data developed by SEA START RC. The Thiessen Polygon methodology and the Spine Interpolation technique were the means in which the calculations for area-averaged climate data including maximum temperature, minimum temperature and precipitation at the province level for NE Thailand. These data offered the study some insight into the patterns of variability of current and projected climate in NE Thailand. In addition, these data were further utilised as the input data for the Ricadian model in the climate change impacts assessment in chapter 6 as well as the criteria layers for the geographic CCR 'hotspot' analysis for NE Thailand in chapter 7.

Chapter 6 reviewed the Ricardian model's application in farming and climate change research. As the main aim of this thesis is set to assess the economic impact of climate change and climatic variability on agriculture in NE Thailand, the climate response functions which are the panel regression analyses using farm-level net revenue, were therefore examined to understand the impact of climate change on agriculture in NE Thailand. In addition, the spatial econometric analysis to estimate the spatial panel models was carried out in order to correct for the heteroscedasticity in the spatial analysis. One of the more significant findings to emerge from this study is that the assessment of climate change impacts on NE Thailand agriculture through a careful consideration of spatial issues in the Ricardian framework that this study has undertaken would be useful in providing a more accurate picture of the potential impacts of climate change on agriculture in NE Thailand.

Finally, chapter 7 assessed the adaptation to climate change for NE Thailand agricultural sector. The geographic CCR 'hotspot' analysis provided a useful analytical tool to explore where future climate stressors may have the greatest impact within NE Thailand and to examine how the existing planned adaptation for agriculture in NE Thailand can alleviate the risk from climate change impacts on agriculture in the region. This chapter highlighted the significance of the implantation of the key planned adaptation, the IWRM plans for Kong (Isan)-Chi-Mun River Basins. In addition, this thesis recommended the adaption measures and policies for climate change in NE Thailand agricultural sector.

8.2 Limitations of the results

There are three main limitations that need to be considered when discussing the results of this thesis. First, there was an unforeseen problem with the dataset used for the purpose of the economic impacts of climate change assessment. This study employed official statistics and a comprehensive province level dataset for the 1984 to 2010. However, the survey of literate population started in 2002 and it has been collected every year, while farm households per hectare own bullocks, small tractors and cultivators have been collected since 1990 and the surveys are done every two years. According to these survey schedules, there are inevitably the missing data included in the dataset. Therefore, it is necessary for this thesis to impute 20 datasets for incomplete cases of these data.

Secondly, provinces are the lowest administrative unit at which reliable agricultural data are available in Thailand and NE Thailand agricultural data available at the duration of the data collection in this research were for the 1984 to 2010. However, three of these provinces were established after 1984, including Nong Bua Lam Phu, Amnat Chareon and Bueng Kan provinces. There is no data available for Bueng Kan province as this province was established in 2011. The data for Nong Bua Lam Phu and Amnat Chareon provinces are available from 1994, thus the time-series exclude ten years of the data. In order to retain the long period of the dataset, which enables the analysis to explicitly detect the impact of climate variables on the farm-level net revenue, the data of these two provinces were integrated back into their original provinces: Nong Bua Lam Phu province data were integrated into Udon Thani province data and Amnat Chareon province data were integrated into Ubon Ratchathani province, respectively. Therefore, the province-level dataset of this study covers only 17 provinces. These may distort the results of these provinces.

Finally, as provinces are the lowest administrative unit at which reliable agricultural data are available in Thailand, this also led to another limitation for this study to analyse the classic single cross section Ricardian model. The single cross-sectional dataset is the average of the data over the entire period of analysis (1984-2010). In order to estimate the farm-level net revenue per hectare (NR) in equation (11) in chapter 4, there are 26 variables involved. As there are 17 provinces in the dataset, the single cross-sectional dataset, therefore, consists of 17 observations. Hence, it is unable to estimate the dependent variable, NR, since the numbers of observations are less than the independent variables.

8.3 Future research possibility

There are a number of research areas related with the economic impacts of climate change on agriculture. As mentioned in chapter 1, the benefit of the study on economic impacts of climate change on agriculture in NE Thailand is to apply for assessing the economic impact of climate change and climatic variability on agriculture of other regions in Thailand. In addition, the findings of this thesis may support 20 Provincial Administration Organisations in NE Thailand to incorporate climate change impacts and climate change adaptation aspect into their provincial development planning processes.

As discussed in the limitations section, due to a lack of reliable agricultural data at a smaller administrative unit than province, it was previously very difficult to quantify agricultural productions and revenues at district, sub-district or village level in Thailand using secondary data. A future research interest would therefore consider the Ricardian analysis if the agricultural data at the smaller administrative unit are available. This would be useful for the local administration organisation to examine the impact of climate change at the district, sub-district or village and design an adaptation at the community level.

The Ricardian approach can be used to assess the impact of climate change on livestock (Seo and Mendelsohn, 2008b). This study applied The Ricardian approach to estimate the impact of climate change on agriculture in NE Thailand considering tillage agriculture as the only source of income of farmers. Thus, the different sources of income such as livestock or integrated sources of income between crops and livestock are recommended.

In terms of climate change scenarios, as mentioned in chapter 5, the RCP scenarios have only been released recently, there has been no set of RCP scenarios for Thailand developed to date. This is a considerable knowledge gap in climate change study in Thailand and specially in NE Thailand.

In terms of climate change adaptation, there is an emerging opportunities for the study of ecosystem based approaches to adaptation. Ecosystem-based adaptation (EBA) integrates the use of biodiversity and ecosystem services into climate change. To enhance the sustainable management of natural resources and conservation and restoration of ecosystems, the study of EBA would provide a useful analytical tool for a researcher.

In summary, to assess the impact of climate change on agriculture in NE Thailand, this study developed long-term climate change scenarios for NE Thailand under the SRES A2 and B2 climate change scenarios for 2020s, 2050s, and 2080s based upon data from the SEA START RC. These scenarios were used to assess the economic impacts of climate change on the regional agricultural sector through the projected changes in farm-level net revenue as climate change using the Ricardian framework with the consideration of spatial issues in NE Thailand. In addition, these scenarios were used to evaluate the planned adaptation measure through the geographic CCR ‘hotspot’ analysis using the Weighted Sum Overlay approach. The findings of this study indicated that NE Thailand agricultural sector is at risk to climate change and therefore, the implementation of climate change adaptation measures such as the integrated water resources management projects are recommended.

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Table A1 Observed farm-level net revenues by province ($/ha)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	243.8	138.9	150.6	247.9	176.4	192.8	123.8	131.3	155.0	326.5	226.8	104.8	140.6	151.3	112.9	13.1	84.3
1985	53.9	21.0	29.1	-251.2	-62.1	13.9	27.2	52.8	-95.3	57.5	56.0	12.3	33.4	-17.5	-146.0	23.7	-101.8
1986	113.6	-1024.0	42.1	126.9	-22.0	338.2	-673.4	102.3	74.5	211.1	183.0	30.1	56.0	49.9	104.3	61.0	-110.7
1987	323.2	178.0	101.6	216.6	313.6	111.3	313.6	198.8	236.6	288.6	272.7	62.0	90.3	85.9	138.7	124.7	107.7
1988	609.7	271.7	162.0	571.7	436.3	193.7	357.3	356.5	449.6	457.5	327.4	265.3	143.3	341.3	231.0	157.2	200.7
1989	908.5	280.5	159.6	306.6	620.4	254.9	555.8	488.2	544.2	620.3	323.7	365.1	164.6	424.4	254.6	271.8	238.5
1990	842.6	321.2	162.4	1178.1	446.7	335.6	677.6	389.9	622.0	604.9	285.9	390.8	290.0	397.3	425.1	298.0	504.5
1991	873.1	515.8	269.1	4145.5	398.5	396.0	813.4	589.6	619.3	616.2	433.4	489.6	394.9	512.9	368.7	401.7	380.2
1992	-1446.3	379.3	227.8	4470.4	583.6	364.6	718.2	561.6	562.9	-100.8	-565.5	389.8	458.9	463.6	306.4	355.7	267.4
1993	-950.3	3060.6	1537.3	5704.3	412.5	157.6	1898.5	451.2	583.9	-39.8	-1000.0	205.1	161.8	294.6	298.1	1881.9	256.2
1994	78.1	512.3	202.7	4102.4	892.0	1098.3	640.4	469.1	2093.4	448.5	-156.4	437.7	247.3	410.2	1378.2	2083.0	638.7
1995	2067.8	2448.2	575.8	6313.1	2396.8	542.8	3311.8	917.3	3440.8	263.0	185.3	710.9	767.3	812.4	814.1	4186.4	825.0
1996	3411.6	5439.2	6446.0	9586.9	4797.3	5529.3	5725.3	2965.4	4909.7	1450.6	2475.1	2664.6	2874.7	2744.1	2326.6	7816.1	750.8
1997	2391.6	2510.9	2613.7	4533.3	2935.9	2958.1	3134.5	2631.9	4125.5	1172.9	2481.6	2358.0	2079.0	2464.3	3353.9	4358.2	521.5
1998	1760.3	2829.6	2651.7	2828.2	2610.9	2504.4	3105.4	2415.7	3883.6	2868.1	3026.7	2367.8	1948.4	2301.6	3030.1	3197.7	237.8
1999	1446.0	3314.3	4227.3	5756.0	2858.3	2674.0	2035.5	2524.5	1901.4	1824.8	1824.0	2167.2	1800.3	2160.6	1794.2	1792.9	2398.4
2000	1067.0	996.4	912.6	2851.2	956.7	564.4	2076.5	2108.5	1166.7	1213.6	524.5	1807.8	1291.7	1643.3	1519.1	885.0	2030.2
2001	2455.5	1791.2	883.1	1020.0	494.3	1034.7	4930.9	1940.5	-396.3	1641.7	653.0	1503.7	1105.7	1268.9	1684.5	959.6	1691.8
2002	2602.4	2674.4	1460.7	2345.6	1075.2	2031.2	4612.7	1716.3	-117.5	1074.4	1653.2	1370.5	889.8	934.3	1960.9	1337.4	1462.1
2003	1044.7	2486.8	1206.9	760.5	353.0	1087.2	2452.2	1582.3	-1970.0	826.2	1728.4	1053.1	355.5	509.0	1862.3	753.3	808.2
2004	380.8	1583.2	168.6	-917.1	-414.5	35.5	1126.4	1783.1	-175.6	4599.8	3933.3	613.5	-258.9	95.1	3903.7	1641.7	527.6
2005	230.6	987.3	-3.9	-679.7	-25.4	1039.0	1173.9	617.0	1024.4	4272.8	3654.0	-19.6	-614.5	698.2	3482.9	2529.7	406.1
2006	540.9	1633.1	1388.1	2466.7	1791.0	3908.1	3300.6	166.4	-1845.9	4981.4	4058.5	-763.9	-948.4	-717.6	3575.9	981.4	46.3
2007	2911.9	2379.1	1259.7	2649.7	1898.2	1923.7	4378.9	1579.0	1906.5	6192.5	3847.4	-929.7	-375.8	532.2	1990.5	2187.0	435.0
2008	2811.2	5752.3	1615.4	4422.3	3739.3	5087.9	7469.0	2886.7	4568.5	9268.4	3531.7	-1106.8	-194.6	3713.8	5430.8	5457.8	821.1
2009	1894.9	5937.7	2548.3	4344.4	3654.8	6168.4	6138.9	2246.0	5206.8	10689.1	2482.8	157.0	325.5	3557.5	7193.7	4623.8	1390.8
2010	2380.9	1923.6	-1942.5	4987.4	-998.4	-1335.3	4659.8	1441.2	325.9	5877.0	1489.7	-1266.5	-1532.1	1308.9	5366.0	6825.7	-839.6

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A2 The Northeast Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	543	762		166		-312	105	1438	-18			36					
1985	600	-363		-140		405	84	-238	-358			-283					
1986	596	1166		-180		208	215	-615	-83			-1644					
1987	492	1604		44	518	258	411	-455	354			-62					
1988	1389	626		280	532	345	992	617	545			207					
1989	1805	445	1297	386	366	882	490	100	1038	-320		293					
1990	975	969	1826	135	323	1060	596	-42	1427	-472		1375					
1991	1298	1432	2084	227	659	1098	493	945	435	1177		2370					
1992	1382	1372	1614	308	501	997	573	706	570	3427		550			-4699		696
1993	618	643	606	264	530	881	668	337	842	5041		7702			-3699		481
1994	818	896	1439	442	1023	1108	1609	542	1924	946		5407			-2304		964
1995	1053	2817	2379	1004	1027	1568	877	3405	1574	10314		4916			-2987		1433
1996	1869	2399	2340	984	1183	2300	1038	2036	834	16181		15745	25739		-2576		2759
1997	1466	399	1363	945	693	1882	845	466	1966	7391	1152	3240	26030	175	-3010		2538
1998	1445	1525	1113	313	521	1232	327	-230	-118	-1998	2332	9524	25631	192	-504		3181
1999	1456	702	1913	689	731	972	315	929	139	2901	543	12110	27429	58	-6350		1015
2000	928	-130	1356	478	730	1011	433	1440	629	1767	589	930	21034	217	-5091		349
2001	876	-70	1367	465	670	1247	241	843	-591	5609	1587	2708	20389	-687	-7129		193
2002	1132	1215	1251	616	396	1225	335	175	-241	5928	1553	6558	14413	-735	-3262		1579
2003	1045	1383	1800	764	342	1878	700	205	28	3230	2732	5550	2702	-818	-3936		2471
2004	1455	1139	819	769	594	2112	318	-87	-273	2097	3639	11	-1240	-998	-3351	12677	2122
2005	1471	2310	1182	799	425	2056	425	-176	-343	1601	3258	386	409	-1084	-3686	12073	1165
2006	1859	3509	2779	1113	528	1718	508	1049	-325	3212	8619	13937	-6140	-1000	-3735	-363	857
2007	2560	3811	3511	1554	833	2555	652	1088	169	5954	2635	7158	-937	-1002	-2891	7588	3092
2008	4526	8078	4211	2219	629	3468	1179	1095	18	4841	3621	22108	-5057	-733	-5549	21052	3131
2009	4432	4707	5321	1583	969	3711	819			3390	7142	20786	3925	-943	-3535	16034	3780
2010	4236	7620	8216	3324	1062	4017	1251			12979	4134	6896	-26869	-768	-11469	13032	4571

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A3 Nakhon Ratchasima Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	32	72		7		-16	27	66	55								
1985	35	-17		-16		47	21	-12	-4								
1986	37	60		-39		30	36	-50	41								
1987	31	104		-13	48	25	58	-29	99								
1988	107	32		25	47	25	104	31	238								
1989	145	36	132	26	47	68	54	5	397								
1990	64	61	146	3	38	77	48	2	403								
1991	66	104	139	7	70	59	108	86	234								
1992	126	81	143	10	44	55	45	46	222						-2220		
1993	43	42	60	17	53	65	126	16	187	196					-1756		
1994	56	61	139	28	57	73	67	26	418	162					-1009		
1995	64	164	171	129	125	99		144	336	1931					-1095		
1996	85	156	169	106	133	124		71	231	2550			393		-607		
1997	87	39	95	59	57	106	54	10	407	1521			794	441	-1279		
1998	106	106	55	28	48	67	39	-27	65	-455		367	1166	371	-176		
1999	80	57	103	61	72	57	41	36	98				1245	120	-525		
2000	74	1	86	34	63	56	48	63	67				1113	116	-654		
2001	70	18	78	37	53	64	24	4	-98	2107			1040	-332	-609		
2002	70	95	64	44	28	69		-21	-42	2483			768	-345	-611		
2003	89	88	95	66	34	93		-6	-8	1197			465	-332	-736		
2004	111	77	43	77	67	107		-25	14	682			118	-350	-563	24	
2005	120	125	63	77	53	93		-49	75	469			272	-411	-590	-67	
2006	142	229	153	113	61	79		53	37	982			407	-339	-620	-757	
2007	179	237	234	154	120	108		45		1879			603	-469	-503	325	
2008	303	435	266	225	109	136				1171			464	-395	-938	1035	
2009	305	263	295	163	160	175				800			872	-448	-586	-105	
2010	283	366	481	319	170	188				3124			-154	-522	-1875		

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A4 Buri Ram Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	29	47		7		-15		71									
1985	33	-25		-13		42		-16									
1986	35	75		-35		24		-19				-1105					
1987	30	99		-13	43	8	41	-32									
1988	92	38		5	41	27	60	8									
1989	55	24	99	21	45	49	1	-14									
1990	50	60	116	-5		56	42	2									
1991	80	98	144	-17	90	73		48									
1992	81	91	106	-15		98		19									
1993	67	46	47	-9		60		4		2361		485					
1994	55	58	91	-3	58	55		36				163					
1995	45	186	166	17	83	88		171		1904		-210					
1996	72	136	126	43	112	136		81		2751		684	1298				
1997	56	34	90	58	57	94		13		998		-373	1483				
1998	46	89	71	14	41	64		-14				1234	1284				
1999	113	29	111	43	59	51		67				1903	940				
2000	35	-11	73	29	57	53		109				-84	735				
2001	15	-3	78	36	54	68		66				215	1262				
2002	32	64	64	46	32	61		29				1190	1156				
2003	36	82	96	67	32	87		22				1324	739				
2004	52	80	44	88	64	114		3				87	281			770	
2005	55	131	63	87		110		35				97	-582			992	
2006	68	203	139	121		88		-37				2461	-1180			-231	
2007	106	228	227	163		149		126				1579	-1243			1045	
2008	198	460	255	228		228						3991	-2382			2774	
2009	222	269	308	158		218						3150	-1264			2878	
2010	210	343	481	304		221						749	-3739			3354	

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A5 Surin Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	33	55				-23		85									
1985	35	-28				19		3									
1986	34	71				29		-20				-72					
1987	29	80				15		-22									
1988	60	30				16	53	2									
1989	94	12				59	-11	5									
1990	44	51				59	20	-11									
1991	100	81				56		32									
1992	85	78				45		20									
1993	40	36				38		22				1401					
1994	40	63				62		38									
1995	57	148			113	82		176									
1996	37	128	100			101		68		1947		2679	1385				
1997	91	18	62			127		4		760		447	1105				
1998	47	51	68			58		-6		-477		1969	943				
1999	36	14	105			45		70		958		2207	793				
2000	39	-12	74			47		104				106	556				
2001	45	-8	79			58		66				-18	661				
2002	56	51	69			61		34				769	420				
2003	55	46	102			86		21				361	536				
2004	76	29	47			91		1				-281	204				
2005	75	101	60			83		-5				-276	-43				
2006	94	143	148			74		114				1616	-801				
2007	122	184	207			159		190				903	-504				
2008	219	422	252			202		211				3038	-2729				
2009	180	244	303			182						3121	-1483				
2010	208	337	470			195						874	-4026				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A6 Si Sa Ket Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	33	49		41		-2		90				36					
1985	34	-17		2		27		-14				-283					
1986	34	80		-6		26		-26				18					
1987	28	118		40	52	36	31	-26				-62					
1988	65	52		35	41	42	77	52				207					
1989	117	30		65		55	40	25		-320		293					
1990	50	56		39	38	68	9	14		-472		1375					
1991	67	97		111	116	101		107		1177		2370					
1992	40	94		87	66	92	48	67		3427		550					
1993	33	40		38	72	64		44		1742		3671					
1994	24	46		58	82	74		50		541		3227					
1995	39	151		111	98	102		208		2919		2685					
1996	67	148		136	104	153		103		3843		4519	515				
1997	77	27		135	76	114		20		2350		1268	731	-266			
1998	34	111		50	52	77		6		-135		1853	958	-179			
1999	50	38		97	77	64		87		1943		3685	874	-62	-1096		
2000	45	1		66	80	64		124		1767		802	460	101	-658		
2001	41	-4		48	78	78		80		1115		680	422	-355	-1164		
2002	50	67		75	54	77		42		1171		1443	82	-390	-325		
2003	45	58		84	51	100		25		1005		1196	-913	-485	-406		
2004	66	37		101	74	132		8		789		186	-1353	-649	-308		
2005	69	95		101		126		-39		500		194	-730	-674	-322		
2006	84	164		135		108		42		1029		2762	-895	-661	-302		
2007	115	200		188		154		88		1932		1139	-383	-533	-249		
2008	209	439		237		236		120		1191		3713	-880	-338	-505		
2009	176	253	322	189		255				984		3104	-132	-494	-311		
2010	194	367	460	368		268				3454		2147	-1030	-245	-994		

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A7 Ubon Ratchathani Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	35	26		25		-24		69	45								
1985	38	-21		-1		29		-24	-82								
1986	37	55		-5		9		-44	-25			-49					
1987	28	123		51	55	17		-32	72								
1988	65	52		41	50	33		1	193								
1989	87	36		59	61	61	-3	-22	343								
1990	40	55		35	50	89	4	-19	192								
1991	33	91		79		74		37	85								
1992	68	104		59	62	83		67	142								
1993	22	40		57		50		36	208								
1994	66	45		61	64	107	48	73	277								
1995	75	297		135	75	143		313	103			931					
1996	123	244		150	161	258		202	149			1972	3334				
1997	100	50	65	146	93	210		51	315			508	3194				
1998	93	128	39	31	69	135		-43	-42			798	3199				
1999	130	74	100	69	96	109		84	41			1902	3060		-1011		
2000	55	-10	68	54	99	112		141	131			-85	2589		-403		
2001	46	-12	72	47	92	141		88	-55			-58	2718		-788		
2002	88	112	69	70	63	152		72	17			371	2349		-494		
2003	62	101	99	83		208		66	56			658	1405		-591		
2004	95	86	48	100		242		13				-375	1662		-490		
2005	67	212	69	104		239		17	-18			-370	2021		-512		
2006	135	341	170	155		205		118	3			1314	1792		-523		
2007	213	397	176	210		292		96	109			695	2042		-414		
2008	384	865	236	274		346		141				2906	1339		-835		
2009	380	520	285	193		439						3471	817		-533		
2010	423	995	440	534		468						1130	-1346		-1724		

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A8 Yasothon Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	34	56				-25		128									
1985	35	-18				14		-17									
1986	36	52				3		-33				281					
1987	31	100				15		-35									
1988	91	44				16		42									
1989	115	27	69			53		-9									
1990	67	63	143			63		-1									
1991	71	83	132			65		45									
1992	96	113	78			32		45									
1993	45	48	-5			41		29									
1994	50	72	97			42	802	36									
1995	71	142	138			62		131									
1996	153	114	134			96		98				2897	2036				
1997	70	12	85			75		27				1176	1512				
1998	122	81	87			54		-15				784	1392				
1999	60	32	135			39		47				2413	1112		-1164		
2000	48	2	77			39		78				190	574		-443		
2001	42	4	82			56		73				813	593		-628		
2002	63	78	70			45		29				1315	585		-155		
2003	61	86	101			116		31				984	-110		-182		
2004	80	75	45			124		9				454	-537		-215		
2005	87	138	65			124		64				622	190		-251		
2006	102	203	174			91		188				3394	5		-249		
2007	136	215	184			138		158				1740	-448		-198		
2008	233	468	240			193						5293	-950		-389		
2009	248	264	289			206						5442	-20		-261		
2010	218	444	441			231						619	-2446		-843		

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A9 Chaiyaphum Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	33	37		6		-18	8	-7	64								
1985	36	-18		-17		28	5	-50	42								
1986	36	54		-37		18	27	-83	27			-716					
1987	28	84		0	59	13	35	-30	125								
1988	81	33		14	63	40	101	6	20								
1989	128	36	111	15	53	54	50	-16	125								
1990	54	60	140	2	47	63	53	5	253								
1991	114	88	136	37	83	61	99	92	104								
1992	117	64	96	27	57	65	78	75	138								
1993	33	30	47	16	57	49	55	34	175	741		661					
1994	44	52	97	89	61	62	71	15	253	359		-465					
1995	63	157	153	113	89	90	88	212	306	2139		-99					
1996	96	140	164	95	103	138	107	140	160	2759		1033	790				
1997	70	29	112	62	60	108	62	26	246	706		-222	1877				
1998	38	99	56	33	58	67	28	-12	-21	-425		1261	1924				
1999	96	46	105	62	76	55	30	56	21				1956		-466		
2000	67	-3	86	36	86	56	40	87	94				1941		-414		
2001	67	2	76	43	69	65	36	7	-117	2388		1076	1868		-650		
2002	49	76	68	52	37	62	38	-11	-120	2274		1470	902		-284		
2003	60	76	98	69	50	77	83	-4	-45	1028		1027	284		-350		
2004	75	67	48	78	85	100	55	-17	-33	626		-61	-179		-283	565	
2005	84	130	69	72	72	103	60	-15		632		119	-23		-302	173	
2006	100	213	164	105	88	86	65	144		1201		2390	-88		-321	-845	
2007	143	211	228	151	133	94	92	131		2144		1103	402		-257	-195	
2008	248	433	274	225	87	159	138	149		1341		3167	229		-506	1526	
2009	246	259	305	140	153	184	129			829		2498	753		-324	967	
2010	230	365	485	305	177	205	228			3160	-90	1377	-692		-1090		

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A10 Khon Kaen Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	32	20		36		-14	7	51									
1985	36	-26		-5		33	15	0									
1986	36	65		-6		-5	34	-23									
1987	30	79		-2	62	-2	59	-28									
1988	84	31		43	52	20	102	24									
1989	137	23	115	67	54	37	57	-3									
1990	42	57	137	29	46	39	55	-14									
1991	98	84	150	-8	99	46	46	75									
1992	103	59	112	33	102	53	51	47									
1993	31	34	163	31	64	45	63	21									
1994	52	56	101	57	75	46	66	15									
1995	77	167	178	74	103	61	104	153									
1996	105	137	176	82	132	106	114	106					2008				
1997	125	17	93	88	61	101	85	31					2030				
1998	98	72	54	14	51	72	28	-13					2040				
1999	105	48	96	39	63	62	32	50					2029				
2000	67	-5	86	31	71	67	44	73					1674				
2001	46	-17	80	35	63	70	25	60					1577				
2002	72	60	80	43	36	75	36	23					1290				
2003	77	65	115	61	39	115	77	15					1018				
2004	96	63	48	76	64	107	39	-24					568			744	
2005	102	140	82	75	57	101	56	-7					-597			608	
2006	117	215	182	110	53	79	70	213					-406			-466	
2007	152	223	259	160	83	128	96	87					324			67	
2008	269	400	287	221	59	206	180	106					193			966	
2009	298	220	322	152	128	207	163						755				
2010	248	387	510	306	141	231	232						-613				

Source Author's calculations based upon data from Office of Agricultural Economic

Table A11 Udon Thani Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	32	58		10		-21	-12	84	4								
1985	33	-32		-4		19	1	-32	-80								
1986	34	61		-22		36	31	-34	-32								
1987	31	110		4	40	24	44	-38	21								
1988	86	45		32	61	5	73	21	126								
1989	90	31	114	43	47	54	56	-5	114								
1990	72	57	142	12	45	90	57	-5	153								
1991	69	97	137	4	103	88	57	53	10								
1992	61	97	95	28	90	58	76	31									25
1993	28	52	55	46	64	74	87	17	116								46
1994	52	58	99	90	195	133	126	40	358								333
1995	102	339	290	215	225	160	207	408	256								364
1996	224	267	319	234	296	236	224	247	94				1099				794
1997	107	49	180	153	194	171	179	93	416				981				725
1998	157	152	126	98	146	115	70	-23	-41				1151				1057
1999	145	86	240	175	195	90	75	114	-24				2891		-1125		298
2000	89	-10	168	122	182	93	102	180	102				2347		-1047		98
2001	104	-5	157	117	175	123	42	107	-166				1961		-1787		35
2002	136	134	158	140	97	106	72	-19	-35				866		-513		
2003	83	178	224	169	78	180	152	-12	21				-1020		-641		
2004	166	135	99	119	159	190	49		-196				-1582		-657	2724	
2005	178	277	140	140	161	167	61		-118				157		-750	2256	
2006	210	429	293	181	221	164	69		-136				-1282		-763	413	
2007	279	427	366	259	342	252	116		-73				1000		-566	1149	
2008	484	880	461	410	245	400	236						1408		-1014	2702	
2009	439	529	560	293	356	386	226						1938		-647	2769	
2010	411	853	866	591	385	444	357						-1255		-2234	1552	

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A12 Loei Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	23	74		34		-17	35	108	68								
1985	32	-7		-7		27	32	5	-25								
1986	28	131		-8		32	46	-27	10								
1987	17	125		-2	55	6	60	-27	54								
1988	60	57		44	79	29	95	45	48								
1989	77	34	111	39	58	72	66	34	130								
1990	61	69	115	2	58	75	54	27	144								
1991	50	91	113	29	98	79	50	59	46								
1992	45	145	87	43	79	64	92	45	12						-713		
1993	31	64	63	34	77	67	63	15	95						-549		
1994	38	71	131	38	100	81	67	25	246						-349		
1995	46	164	191	97	117	124	93	144	155						-868		
1996	165	139	187	87	142	91	106	81	62				1322		-933		
1997	96	31	89	81	95	100	95	41	236				1335		-1027		
1998	59	110	69	17	56	67	47	-27	13		1217		1380		-141		
1999	54	34	113	64	92	56	39	27	31		543		1244		-473		
2000	53	-6	85	50	91	60	49	55	72		589		784		-668		
2001	38	10	81	46	87	71	32	63	-79		1586		528		-821		
2002	73	75	79	55	49	61	44	-57	-14		1020		78		-387		
2003	55	82	112	82	57	100	98		13		1164		-1249		-460		770
2004	81	63	51	68	83	134	19		-58		1768		-234		-370	2300	695
2005	86	136	73	72	82	128	69		-114		1342		377		-423	2058	386
2006	102	160	152	97	105	146	74		-87		3255		667		-442	474	280
2007	131	173	182	133	153	172	106		169		1488		645		-336	2065	1110
2008	229	412	211	202	129	202	192		18		2041		971		-620	4099	1181
2009	226	246	260	159	171	197	175				3816		752		-395	3683	1399
2010	219	430	423	318	189	224	255				2060		-927		-1277	2319	1645

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A13 Nong Khai Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	32	42				-33	40	146									
1985	36	-18		-17		40	20	-4									
1986	36	75		1		44	42	-16									
1987	30	99		-6	55	40	77	-21									
1988	73	41			50	4	111	49									
1989	113	30	87			48	40	6									
1990	59	51	95			38	65	-22									
1991	47	79	139			37	76	55									
1992	86	69	111	43		32	46	34	109						-1766		670
1993	36	28	28	41		10	49	35							-1394		168
1994	43	47	110		64	49	62	26							-946		389
1995	60	101	145			69	58	177							-1024		600
1996	86	95	125			111	81	102					1833		-1036		1078
1997	83	-2	54	107		84	69	26					1778		-704		985
1998	97	60	58	24		52	35						1623		-186		1263
1999	114	16	126	80		40	24						1508		-490		407
2000	37	-26	89	55		41	34						917		-804		182
2001	48	-16	87	55		58	22						966		-681		115
2002	51	45	82	90		54	32						864		-492		927
2003	57	79	114	83		77	66				842		-1		-570		981
2004	79	73	52	61		111	41				1120		18		-464	1904	940
2005	79	128	74	71		112	49				1047		234		-537	1971	426
2006	93	170	152	96		96	54				2792		321		-514	505	292
2007	129	180	183	135		140					1147		30		-368	1268	1003
2008	238	395	233	198									-22		-742	2296	935
2009	240	231	282	135									-190		-478	1133	1130
2010	234	417	424	278									-1569		-1432	1930	1208

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A14 Maha Sarakham Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	32	30				-9		51									
1985	37	-22				25		-28									
1986	37	47				-7		-47									
1987	31	57				-1	-4	-22									
1988	91	20				6	59	89									
1989	146	21	89			52	21	35									
1990	90	62	129			83	28	0									
1991	99	81	189			58	30	32									
1992	110	64	110			48	15	43									
1993	61	31	41			51	26	-6									
1994	70	47	83		126	51	38	23									
1995	79	130	182			82	72	165									
1996	122	124	164			123	86	104					1942				
1997	99	22	80			97	65	14					1981				
1998	129	98	69			79	10	-16					1998				
1999	115	54	111			59	12	51					1764				
2000	72	-4	74			70	21	84					1490				
2001	68	-9	78			68	13	11					1275				
2002	95	66	71			71	21	-4					1050				
2003	89	69	102			72	47	-3					676				
2004	116	55	49			110	44	-19					257				
2005	123	109	72			109	49	-42					-440				
2006	142	173	175			65	59						-1378				
2007	180	190	233			107	81						-1720				
2008	303	415	242			165	144						-2375				
2009	297	224	294			187							-846				
2010	258	372	452			197							-2546				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A15 Roi Et Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	34	21				-16		102									
1985	36	-25				27		-5									
1986	36	76				-12		-44									
1987	31	80				4		-25									
1988	95	25				10	-6	18									
1989	129	5				37		-6									
1990	94	40	94			49	28	-14									
1991	125	52	151			34	-10	42									
1992	105	60	177			41	57	18									
1993	27	25	0			49	53	9									
1994	50	44	53			45	24	32									
1995	82	142	125			75	127	216									
1996	120	115	155			127	145	148					2065				
1997	77	23	62			106	84	21					1706				
1998	132	112	57			70	27	-19					1570				
1999	91	66	112			52	31	50					1398				
2000	64	5	78			55	46	76					968				
2001	80	3	86			56	-10	39					851				
2002	105	76	75			64	35	14					520				
2003	67	78	109			114	61	16					-89				
2004	92	51	51			103	39	0					-595				
2005	115	116	73			106	43	-87					-982				
2006	133	177	176			85	59						-1577				
2007	182	201	237			129	82						-1207				
2008	297	439	250			187	147	185					-1700				
2009	296	235	301			207							-713				
2010	246	391	465			231							-2865				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A16 Kalasin Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	31	61				-17		77									
1985	34	-24		-27		14		-14									
1986	34	55		-11		-5		-22									
1987	26	105		-2		16	-21	-39									
1988	85	36		42		37	64	77									
1989	128	28	102	51		53	25	38									
1990	92	58	136	18		55	39	1									
1991	113	86	180	-15		61	36	52									
1992	110	72	150	15		53	34	29									
1993	47	36	52	14		70	61	15									
1994	41	53	141	23		54	54	44									
1995	77	137	171	113		77	60	177									
1996	125	125	145	52		119	75	109					1994				
1997	77	22	85	56		102	57	26					2039				
1998	115	80	76	4		67	22	-12					1951				
1999	126	69	116			49	12	60					1729				
2000	89	9	77			53	21	75	163				1156				
2001	73	3	83			67	27	51	-76				1041				
2002	66	73	76			68	23	13	-47				663				
2003	75	110	110			134	54	5	-10				31				
2004	101	92	49			140	31	-18					-530			231	
2005	112	142	73			136	39	-31					-329			556	
2006	110	233	182			100	57	122					-1298			-224	
2007	168	236	254			137	79	98					-792			353	
2008	294	454	278			216	141	116					761			1453	
2009	305	287	314			226	126						1091			1208	
2010	251	369	475			248	180						-215				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A17 Sakon Nakhon Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	31	58				-29		136	-84								
1985	37	-33		-33		18	-10	9	-133								
1986	36	58		-13		9		-42	57								
1987	30	91		-14	49	16	16	-31	-18								
1988	68	37			48	15	72	73	-81								
1989	73	29	108			48	-3	20	-19								
1990	23	53	125			76	43	-5	110								
1991	88	68	127			87		43	-45								
1992	38	52	105	-22		48	31	37	19								
1993	26	39	3	-21	141	55	53	-5	8								
1994	36	45	89		140	61	55	17	122			813					
1995	42	140	162			98	67	201	103								
1996	71	108	125			136	99	126	33				1628				
1997	58	10	69			94	94	26	123		1152		1727				
1998	74	73	75			63	20	-13	-68		1115		1691				
1999	50	19	106			45	20	53	-38				1539				
2000	26	-14	75			47	29	79					1277				
2001	43	-10	80			72	31	52			1		1416				
2002	51	48	71			66	33	22			533		1136				
2003	46	69	103			116	62	22			726		717				
2004	42	49	46			99					751		751			2165	
2005	35	116	67			102					869		699			1595	
2006	66	158	153			83					2571		331			214	
2007	110	180	159			127							773			641	
2008	223	406	222			188					1580		1042			1770	
2009	214	218	273			208					3326		1093			1861	
2010	217	392	406			231					1888		85			2147	

Source Author's calculations based upon data from Office of Agricultural Economic

Table A18 Nakhon Phanom Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	36	33				-23		52	-84								
1985	37	-11				17		-19									
1986	36	64				-3		-36									
1987	31	65				7	15	7									
1988	86	16				19		37									
1989	86	14	75			42	50	5									
1990	41	57	168			38	0	-6									
1991	37	70	192			52		49									
1992	46	63	131			58		58									
1993	23	19	46			38	-23	29				1483					268
1994	37	37	73			56	66	17		-116		1669					243
1995	41	110	174			70		172	122	1421		1607					469
1996	85	115	127			116		100		2330		1961	2095				887
1997	96	9	78			90		11		1055		435	1756				828
1998	48	35	77			63				-505		1258	1362				861
1999	49	-5	117			43							1278				311
2000	38	-27	81			44							680				69
2001	31	-12	87			63							749				42
2002	48	45	76			68							448				652
2003	46	67	110			77							-266				720
2004	64	45	48			90							-343			1251	487
2005	64	97	68			96							-78			1931	353
2006	77	149	190			86							-359			555	285
2007	106	168	194			123							-254			870	979
2008	191	380	248			193				1138			-137			2430	1015
2009	177	210	296			196				777			78			1639	1251
2010	203	373	453			217				3242	276		-1387			1731	1718

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A19 Mukdahan Province Net Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	31	24				-11		127	-87								
1985	35	-20				-20		-20	-76								
1986	33	88				-20		-49	-162								
1987	30	84				18		-24									
1988	100	35				0	25	41									
1989	86	29	87			39	47	3	-52								
1990	32	58	143			43	52	6	171								
1991	40	84	153			67		37									
1992	65	67	114			71		23	-72								
1993	27	34	8			54	56	23	53								
1994	64	41	137			56	61	29	251								
1995	33	140	134			88		236	194								
1996	134	107	125			128		151	105								
1997	96	11	63			102		26	224								
1998	49	67	77			63		5	-23								
1999	42	27	118			55		76	11				2070				
2000	32	-19	80			54		111					1772				
2001	18	-15	83			69		76					1460				
2002	26	52	77			65		7					1235				
2003	41	50	110			125		5					478				
2004	63	62	51			117		-19					254				
2005	20	118	71			119		-17	-168				263				
2006	84	150	177			83		92	-142				-398				
2007	110	164	187			147		70	-37				-205				
2008	203	375	257			210		66					-289				
2009	182	235	312			238							423				
2010	181	419	484			216							-2141				

Source Author's calculations based upon data from Office of Agricultural Economic

Table A20 The Northeast Gross Revenue by crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	3135	5754		1912		3093	1510	6388	3228			2332					
1985	2391	3318		1704		5396	1671	3347	2294			1922					
1986	2437	6627		1602		4763	1765	2662	2720			11602					
1987	3805	7575		2166	1665	4921	3485	2952	2990			2206					
1988	10172	5458		2385	1693	5201	5253	4898	3287			2550					
1989	11436	5067	9072	2652	1173	6924	4301	3959	4457	1267		2661					
1990	8538	6201	11313	2020	1086	7498	4757	3702	5061	1045		4048					
1991	10311	7203	12237	2251	1764	7619	3042	5493	3116	3457		5324					
1992	9787	7073	10551	2828	1445	7295	3650	5060	4139	6750		2991			7644		2942
1993	7512	5496	6934	2717	1502	6923	4081	4390	4154	14317		21299			6034		3484
1994	8964	6043	9924	2978	2807	8133	6895	5206	6238	8325		18357			3790		4282
1995	11704	10682	13635	4389	2692	9609	4144	10403	6103	23768		17727			4888		5057
1996	15131	9779	13837	4340	2945	11958	4518	7919	4548	34088		36180	3823		4227		7247
1997	13629	5451	10668	4429	1956	10616	4281	5069	6304	21226	3541	20149	3714	7730	4925		6882
1998	10965	7887	9771	2841	1610	8532	3078	3361	3074	5752	7131	30489	3863	7801	891		7944
1999	10565	6107	12645	3599	2032	7697	3051	5464	3472	7716	2486	26950	4770	7223	10464		4366
2000	8532	4305	10643	3069	2031	7821	3324	6391	3824	4321	2567	12617	7151	7908	8436		3266
2001	8390	4435	10683	3035	1910	8578	2879	5309	1933	13414	5841	17182	7391	4010	11717		3007
2002	9593	7216	10267	3415	1357	8508	2886	4096	2475	13880	5781	22118	9614	3802	5492		4401
2003	10063	7580	12238	3786	1185	10604	3734	3705	2892	9932	9370	20825	13973	3443	6578		6771
2004	12646	7051	8717	3799	1694	11354	2636	2731	1612	8273	10940	13725	15440	2665	5635	35637	6194
2005	12699	9586	10021	3874	1230	11174	2885	2569	1504	7548	10280	14206	14826	2293	6175	34887	4614
2006	14702	12179	15751	4663	1437	10092	3076	4127	1531	9906	19564	31577	17263	2657	6254	19460	4105
2007	18214	12834	18378	5770	2051	12777	3200	4197	1890	13918	7655	22887	15327	2647	4895	29323	7796
2008	24559	22066	20892	7441	1641	15467	4421	3765	435	14024	9363	42051	16860	3808	9173	46026	7861
2009	29012	14773	25217	5844	2326	16247	3165			11901	15460	40358	13518	2904	5931	37810	8932
2010	26468	21076	35609	10215	2514	17227	4168			25933	13343	22551	24978	3661	18703	28113	10240

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A21 Nakhon Ratchasima Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	181	397		205		189	274	343	492								
1985	140	206		146		393	259	200	401								
1986	123	371		90		336	293	131	471								
1987	191	467		154	158	320	346	169	561								
1988	655	310		251	157	323	451	279	776								
1989	759	319	813	252	157	458	336	231	1022								
1990	412	374	863	193	139	490	322	226	1032								
1991	582	467	837	205	204	430	461	379	769								
1992	689	417	852	213	151	419	315	306	751						3601		
1993	447	332	556	230	169	450	502	251	698	2023					2853		
1994	491	373	838	258	178	475	367	269	1054	1972					1650		
1995	675	597	954	512	315	557		484	927	4560					1789		
1996	786	579	946	454	330	639		350	765	5467			642		1003		
1997	757	325	681	334	177	582	336	240	1038	3961			493	5391	2085		
1998	654	471	535	256	159	457	302	173	508	1069		2756	354	5089	311		
1999	554	365	711	340	208	424	305	288	558				325	4004	871		
2000	511	243	648	273	190	421	321	336	511				374	3987	1080		
2001	468	280	619	280	168	447	267	230	255	4818			401	2054	1008		
2002	532	447	570	298	119	464		184	342	5369			503	1997	1011		
2003	622	432	680	351	132	538		211	395	3487			615	2052	1212		
2004	775	408	493	380	196	584		176	429	2733			745	1978	934	2021	
2005	810	511	566	380	168	540		133	524	2421			687	1713	977	1908	
2006	891	737	888	471	186	495		318	465	3172			637	2024	1025	1052	
2007	1069	754	1180	572	305	587		305		4484			564	1462	837	2394	
2008	1460	1183	1294	752	281	679				3449			616	1780	1537	3275	
2009	1682	811	1398	597	386	802				2906			464	1551	970	1861	
2010	1403	1032	2068	989	405	845				6306			846	1233	3045		

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A22 Buri Ram Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	227	343		205		192		352									
1985	170	187		155		374		194									
1986	143	403		100		319		188				869					
1987	207	456		155	149	268	307	165									
1988	604	325		199	145	326	351	237									
1989	504	293	696	239	154	399	213	196									
1990	485	372	755	175		419	309	226									
1991	580	453	858	143	243	476		310									
1992	542	438	722	148		554		257									
1993	510	341	508	164		434		230		5190		2907					
1994	511	366	666	180	180	416		287				2494					
1995	606	644	936	229	229	522		532		4521		2016					
1996	716	536	792	294	289	678		369		5760		3162	305				
1997	623	315	664	332	177	541		246		3196		1807	236				
1998	499	434	593	222	145	447		197				3867	310				
1999	683	303	738	294	181	405		343				4725	439				
2000	427	218	601	260	176	412		421				2177	515				
2001	358	236	619	278	170	460		343				2561	319				
2002	432	380	570	303	127	435		275				3811	358				
2003	471	419	685	356	127	521		263				3982	513				
2004	594	414	497	408	191	608		228				2397	684			2947	
2005	636	524	565	405		595		287				2409	1005			3222	
2006	698	680	838	492		523		155				5441	1228			1705	
2007	876	734	1153	597		718		451				4309	1251			3288	
2008	1178	1236	1257	758		974						7401	1675			5433	
2009	1508	823	1444	584		940						6323	1259			5561	
2010	1442	984	2065	951		950						3246	2180			6152	

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A23 Surin Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	174	361				168		377									
1985	141	181				301		227									
1986	155	396				333		187				2192					
1987	224	414				289		182									
1988	714	307				292	335	227									
1989	630	268				430	186	231									
1990	476	351				430	257	202									
1991	642	416				419		281									
1992	571	409				387		258									
1993	480	320				364		262				4081					
1994	529	378				439		291									
1995	619	562			290	503		542									
1996	537	519	698			566		345		4585		5719	273				
1997	828	280	561			648		230		2847		2858	377				
1998	443	353	584			426		211		1037		4809	438				
1999	410	271	715			384		350		3137		5114	493				
2000	424	215	605			391		411				2420	581				
2001	452	224	624			427		343				2263	543				
2002	509	352	588			436		285				3271	632				
2003	578	340	706			516		261				2748	589				
2004	716	304	510			532		225				1925	712				
2005	751	460	554			508		214				1931	804				
2006	836	551	872			479		429				4357	1087				
2007	982	639	1082			750		566				3443	976				
2008	1294	1155	1244			889		606				6179	1804				
2009	1462	770	1426			825						6287	1340				
2010	1446	970	2027			866						3406	2287				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A24 Si Sa Ket Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	174	348		290		236		386				2332					
1985	153	204		191		329		197				1922					
1986	158	416		171		326		175				2308					
1987	237	496		289	166	355	282	176				2206					
1988	612	355		276	145	374	390	317				2550					
1989	707	307		350		418	305	268		1267		2661					
1990	539	362		285	139	459	232	248		1045		4048					
1991	597	451		466	296	564		417		3457		5324					
1992	426	444		404	195	536	322	344		6750		2991					
1993	418	327		282	208	448		302		4285		6991					
1994	444	340		333	227	480		313		2527		6422					
1995	580	568		465	261	567		600		6007		5727					
1996	647	562		527	271	732		409		7359		8078	597				
1997	765	300		526	214	608		259		5175		3911	516	2339			
1998	424	482		313	167	489		234		1538		4660	432	2712			
1999	460	323		429	217	446		380		4578		7010	463	3219	1792		
2000	432	243		352	224	445		448		4321		3314	617	3921	1086		
2001	435	234		308	219	492		367		3366		3157	631	1956	1901		
2002	491	385		375	171	488		298		3449		4135	758	1804	551		
2003	540	367		398	164	563		268		3206		3818	1128	1391	680		
2004	703	321		441	211	665		238		2889		2524	1292	687	523		
2005	725	448		440		644		151		2467		2534	1060	580	546		
2006	799	597		525		588		298		3241		5826	1121	633	513		
2007	971	673		659		735		382		4562		3745	931	1185	428		
2008	1268	1191		783		1000		439		3478		7046	1116	2028	839		
2009	1473	788	1494	661		1058				3175		6264	837	1353	527		
2010	1397	1036	1989	1110		1102				6789		5037	1172	2427	1627		

Source Author's calculations based upon data from Office of Agricultural Economic

Table A25 Ubon Ratchathani Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	139	298		250		162		347	477								
1985	111	196		183		334		179	279								
1986	119	361		175		271		142	368			2222					
1987	239	507		315	172	296		164	519								
1988	509	354		290	163	348		224	707								
1989	584	319		335	184	436	204	182	938								
1990	433	360		276	163	525	221	188	705								
1991	414	438		384		477		289	539								
1992	502	466		335	186	506		344	627								
1993	362	328		331		402		287	729								
1994	684	339		341	190	826	321	577	836								
1995	1076	1126		527	213	942		1013	567			3479					
1996	1303	1011		563	386	1309		812	638			4813	336				
1997	1205	590	573	553	251	1154		537	895			2937	388				
1998	940	761	480	264	200	914		366	341			3309	386				
1999	1016	642	701	359	257	830		597	471			4723	438		1654		
2000	736	460	584	323	262	842		700	610			2177	613		675		
2001	732	457	600	305	247	933		604	322			2210	565		1295		
2002	872	726	588	363	190	970		576	433			2761	702		822		
2003	862	702	694	396		1151		565	494			3128	1054		978		
2004	1144	668	513	439		1258		468	0			1804	958		815		
2005	900	942	589	447		1250		476	378			1811	825		850		
2006	1327	1221	949	575		1141		437	411			3969	910		869		
2007	1717	1341	971	715		1420		396	576			3176	817		694		
2008	2255	2355	1187	874		1593		479				6011	1078		1370		
2009	2734	1607	1364	673		1892						6735	1273		885		
2010	2645	2636	1919	1527		1985						3733	2078		2802		

Source Author's calculations based upon data from Office of Agricultural Economic

Table A26 Yasothon Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	161	362				162		455									
1985	140	202				287		191									
1986	132	353				250		162				2645					
1987	200	458				289		159									
1988	607	338				294		298									
1989	671	300	588			412		206									
1990	521	379	854			443		220									
1991	549	420	815			449		304									
1992	627	487	621			342		304									
1993	482	345	322			372		275									
1994	454	397	687			377	2072	287									
1995	602	548	834			440		459									
1996	859	487	823			550		400				5999	31				
1997	685	268	646			480		271				3793	225				
1998	719	417	652			414		194				3291	270				
1999	499	310	824			367		308				5379	374		1901		
2000	450	245	615			366		363				2529	575		740		
2001	451	251	633			422		355				3327	567		1038		
2002	494	410	593			385		275				3971	570		276		
2003	519	428	702			613		279				3546	829		320		
2004	645	403	501			639		239				2867	988		373		
2005	687	540	573			639		338				3083	718		431		
2006	744	680	964			534		564				6636	786		427		
2007	926	706	1002			684		508				4516	955		346		
2008	1235	1254	1200			861						9070	1142		653		
2009	1515	813	1377			901						9261	796		447		
2010	1397	1203	1922			983						3079	1699		1383		

Source Author's calculations based upon data from Office of Agricultural Economic

Table A27 Chaiyaphum Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	168	321		203		184	228	210	507								
1985	130	204		143		330	223	132	473								
1986	132	359		94		300	273	72	449			1367					
1987	240	424		186	182	284	292	167	600								
1988	650	313		221	189	369	445	232	438								
1989	738	320	737	224	169	413	327	194	601								
1990	409	372	841	192	158	442	335	231	800								
1991	796	431	828	279	229	435	441	390	568								
1992	709	379	683	255	178	450	393	359	622								
1993	427	307	507	228	177	398	339	284	678	2819		3133					
1994	569	354	688	411	186	441	377	250	800	2261		1688					
1995	609	582	890	470	241	530	415	607	882	4865		2158					
1996	820	545	930	426	270	684	460	476	654	5773		3610	494				
1997	666	305	741	343	182	586	354	270	788	2768		2000	90				
1998	461	456	541	270	179	456	275	201	374	1112		3902	72				
1999	595	341	716	342	215	416	279	324	440				60		777		
2000	518	234	650	278	235	422	303	381	553				66		694		
2001	510	245	612	295	201	449	294	236	225	5230		3665	93		1072		
2002	446	405	585	317	137	439	300	202	221	5063		4169	453		483		
2003	535	405	693	360	163	488	404	215	337	3239		3602	683		591		
2004	632	387	511	382	233	563	339	191	355	2652		2207	855		483	2692	
2005	663	522	586	369	207	571	351	195		2660		2437	797		513	2206	
2006	741	703	930	449	239	516	362	483		3492		5349	821		543	942	
2007	940	698	1159	566	331	542	424	460		4872		3698	639		440	1749	
2008	1273	1178	1325	751	237	753	531	493		3698		6345	703		841	3884	
2009	1492	802	1435	538	371	831	510			2948		5487	508		549	3191	
2010	168	321		203		184	228	210	507								

Source Author's calculations based upon data from Office of Agricultural Economic

Table A28 Khon Kaen Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	188	285		277		197	227	314									
1985	136	185		175		347	246	222									
1986	129	382		173		226	291	181									
1987	206	412		183	188	234	347	171									
1988	621	308		294	167	306	448	266									
1989	794	292	751	356	171	361	343	217									
1990	454	366	831	259	155	364	339	197									
1991	663	422	878	167	261	389	318	359									
1992	602	370	742	270	269	412	330	308									
1993	376	314	924	263	192	384	358	260									
1994	481	363	701	331	214	388	365	250									
1995	656	603	980	372	269	435	453	501									
1996	839	538	971	392	328	580	474	415					41				
1997	840	279	675	408	185	566	408	278					33				
1998	652	396	534	222	165	472	276	198					29				
1999	647	344	683	285	190	441	286	314					33				
2000	489	231	647	266	206	455	312	356					165				
2001	447	204	629	275	190	467	270	330					201				
2002	535	370	629	296	134	483	295	264					308				
2003	583	382	752	339	142	611	389	249					409				
2004	731	379	513	378	191	586	302	179					577			2914	
2005	756	545	634	375	178	564	341	210					1011			2745	
2006	823	706	993	463	169	496	374	608					940			1412	
2007	996	724	1271	589	230	650	433	381					668			2074	
2008	1360	1106	1369	741	180	903	629	415					717			3190	
2009	1683	717	1497	570	320	906	589						507				
2010	1436	1078	2170	956	346	982	749						1017				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A29 Udon Thani Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	189	368		211		173	184	374	414								
1985	168	171		178		300	214	164	283								
1986	152	373		132		356	282	161	358								
1987	201	479		197	143	319	313	153	440								
1988	381	339		267	184	258	381	261	602								
1989	613	309	748	296	157	413	342	213	584								
1990	552	364	849	217	153	530	342	212	645								
1991	564	451	832	197	270	525	344	318	423								
1992	501	452	680	258	244	429	386	279	407								938
1993	377	353	536	302	192	480	412	253	586								972
1994	656	367	694	600	517	910	713	517	1368								1446
1995	1109	1216	1721	913	577	996	903	1185	1210								1498
1996	1714	1061	1823	962	721	1240	942	893	959				379				2208
1997	1227	589	1327	758	516	1029	838	613	1459				423				2095
1998	1170	812	1131	619	419	852	583	402	750				360				2642
1999	1088	669	1540	813	517	771	596	651	777				501		1865		1388
2000	860	461	1281	679	492	779	658	771	972				703		1738		1059
2001	869	471	1244	668	477	877	518	639	557				847		2931		955
2002	1012	773	1248	724	319	823	588	410	759				1254		880		
2003	989	868	1484	797	281	1059	773	201	847				1956		1086		
2004	1341	775	1034	673	444	1091	536		510				2166		1112	5371	
2005	1411	1082	1181	726	449	1017	562		225				1518		1261	4789	
2006	1556	1410	1731	828	569	1007	583		196				2054		1282	2503	
2007	1907	1406	1994	1025	814	1289	690		295				1205		965	3416	
2008	2586	2387	2334	1403	619	1764	969						1053		1686	5343	
2009	2899	1627	2691	1110	843	1722	945						856		1095	5426	
2010	2661	2329	3788	1858	901	1907	1249						2044		3650	3916	

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A30 Loei Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	296	402		272		188	293	419	513								
1985	185	226		170		327	286	232	369								
1986	236	525		166		344	317	173	422								
1987	374	513		182	172	259	350	173	491								
1988	768	365		297	221	333	431	305	482								
1989	739	314	737	285	180	471	365	283	608								
1990	612	391	752	192	179	483	336	271	631								
1991	751	439	745	261	260	493	327	330	478								
1992	628	554	650	295	222	447	425	303	426						1175		
1993	425	380	567	272	217	456	357	250	555						911		
1994	646	396	811	281	264	502	367	268	788						589		
1995	773	595	1024	432	298	638	427	483	647						1423		
1996	1138	542	1012	406	349	533	457	369	504				296		1529		
1997	878	308	660	391	254	563	431	296	773				291		1680		
1998	667	480	587	231	175	456	320	173	427		3654		275		254		
1999	614	316	744	349	247	422	302	272	454		2486		325		788		
2000	599	229	644	312	246	433	326	321	518		2567		496		1103		
2001	524	263	631	303	238	467	285	336	285		4293		592		1349		
2002	646	403	624	324	160	436	312	119	385		3312		759		651		
2003	588	418	743	393	177	563	439		427		3563		1253		767		2168
2004	698	377	522	357	228	670	255		317		4608		875		622	4844	2045
2005	730	537	603	367	228	653	372		230		3869		648		707	4544	1534
2006	807	587	884	431	274	709	383		272		7183		540		739	2579	1358
2007	970	616	993	521	371	793	458		670		4123		548		567	4552	2731
2008	1324	1134	1098	695	323	891	656		435		5081		427		1025	7076	2848
2009	1585	774	1272	587	407	872	618				8155		509		663	6560	3207
2010	1473	1171	1859	986	443	961	801				5113		1133		2082	4867	3613

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A31 Nong Khai Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	180	331				134	304	488									
1985	133	202		143		369	257	216									
1986	127	403		190		382	309	194									
1987	211	455		172	172	368	389	183									
1988	558	330			163	253	468	310									
1989	690	307	650			395	304	233									
1990	492	352	680			364	362	182									
1991	463	411	840			361	388	321									
1992	550	392	737	294		345	317	284	576						2869		2003
1993	436	302	439	289		274	324	285							2271		1173
1994	467	342	733		190	399	356	270							1550		1539
1995	578	460	859			462	345	544							1676		1888
1996	723	447	789			596	400	407					106		1695		2676
1997	737	236	534	457		511	372	270					127		1160		2523
1998	678	372	549	247		406	293						184		326		2983
1999	674	276	791	388		368	266						227		815		1569
2000	402	185	658	325		373	290						447		1321		1197
2001	398	207	651	324		426	261						429		1123		1086
2002	455	338	634	414		415	286						467		819		2428
2003	510	411	751	396		488	364				3004		789		945		2517
2004	635	399	526	340		598	306				3485		782		773	4353	2448
2005	653	518	606	365		600	323				3360		701		891	4436	1601
2006	749	610	885	428		548	337				6382		669		854	2617	1379
2007	926	630	998	526		691					3533		777		618	3564	2553
2008	1276	1096	1178	684									796		1221	4839	2441
2009	1517	741	1354	525									859		796	3396	2763
2010	1422	1143	1863	885									1372		2333	4385	2892

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A32 Maha Sarakham Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	182	307				213		315									
1985	116	194				321		172									
1986	114	344				218		136									
1987	190	366				237	203	182									
1988	597	285				260	349	384									
1989	762	287	660			409	260	286									
1990	604	376	802			506	275	222									
1991	648	416	1019			428	281	280									
1992	653	380	735			396	245	300									
1993	498	308	489			404	272	212									
1994	536	343	639		316	403	298	264									
1995	690	524	992			504	378	522									
1996	859	511	927			635	410	411					66				
1997	807	289	625			553	362	249					51				
1998	720	453	588			496	235	193					45				
1999	665	359	738			431	240	315					132				
2000	515	233	606			466	260	375					234				
2001	538	222	619			460	240	242					314				
2002	628	384	594			467	261	216					397				
2003	638	390	707			473	321	217					537				
2004	786	361	517			594	314	188					693				
2005	831	476	599			592	324	145					952				
2006	917	615	968			448	348						1301				
2007	1112	652	1176			585	399						1429				
2008	1496	1140	1207			770	544						1672				
2009	1745	725	1396			841							1103				
2010	1525	1047	1961			874							1736				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A33 Roi Et Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	155	286				189		407									
1985	127	188				328		213									
1986	128	405				203		142									
1987	195	414				255		177									
1988	616	296				274	198	255									
1989	717	253				359		211									
1990	608	328	676			397	275	197									
1991	715	353	884			351	188	298									
1992	666	372	976			372	344	254									
1993	432	295	338			398	333	239									
1994	511	336	530			385	267	281									
1995	705	550	788			482	505	614									
1996	847	490	895			650	548	491					20				
1997	744	290	561			582	407	260					153				
1998	735	483	544			466	274	188					204				
1999	586	385	743			408	282	312					268				
2000	486	252	622			417	317	360					428				
2001	578	249	650			420	188	293					472				
2002	663	406	609			447	293	248					595				
2003	565	411	731			605	352	251					821				
2004	723	352	524			570	301	222					1010				
2005	825	493	603			582	311	65					1154				
2006	890	625	971			513	347						1375				
2007	1113	677	1189			655	402						1237				
2008	1477	1192	1237			840	552	558					1421				
2009	1738	750	1419			905							1054				
2010	1492	1088	2009			982							1855				

Source Author's calculations based upon data from Office of Agricultural Economic

Table A34 Kalasin Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	196	373				186		361									
1985	153	189		118		287		196									
1986	157	359		158		225		182									
1987	262	469		182		293	163	152									
1988	675	319		291		361	360	363									
1989	754	302	706	315		412	268	290									
1990	632	367	827	231		416	301	224									
1991	729	428	987	148		437	294	317									
1992	702	397	877	225		411	290	275									
1993	517	320	526	222		464	351	250									
1994	513	357	845	244		414	337	302									
1995	780	539	955	471		488	349	544									
1996	984	511	861	316		624	386	420					46				
1997	798	289	646	327		569	344	269					29				
1998	712	414	611	196		454	263	200					62				
1999	728	390	756			399	238	331					145				
2000	598	261	617			411	260	358	660				358				
2001	532	249	638			456	272	314	289				401				
2002	552	399	612			460	263	246	335				542				
2003	614	480	734			670	336	232	391				777				
2004	785	441	516			690	282	189					986			2277	
2005	856	549	602			679	301	166					911			2681	
2006	875	745	994			563	343	444					1271			1713	
2007	1138	751	1251			680	393	401					1083			2429	
2008	1531	1224	1339			933	539	432					505			3794	
2009	1853	862	1467			968	504						382			3490	
2010	1547	1040	2045			1037	629						868				

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A35 Sakon Nakhon Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	194	367				149		469	277								
1985	123	171		103		298	187	238	201								
1986	134	366		154		269		146	496								
1987	210	438		151	162	292	247	166	379								
1988	425	322			158	289	377	354	282								
1989	585	303	726			394	203	258	378								
1990	423	356	790			486	310	212	577								
1991	617	389	796			521		300	338								
1992	435	353	716	131		393	283	290	436								
1993	438	326	350	134	347	418	334	212	419								
1994	459	339	659		344	437	338	253	596			3328					
1995	530	545	920			556	367	588	566								
1996	712	476	788			677	441	452	458				182				
1997	629	264	589			544	429	269	598		3541		146				
1998	542	400	609			442	257	199	302		3477		159				
1999	462	283	719			387	258	319	348				216				
2000	321	212	609			392	277	366					313				
2001	403	219	628			471	283	316			1549		261				
2002	467	346	594			454	288	262			2469		365				
2003	483	392	710			613	356	262			2804		521				
2004	543	348	507			558					2847		509			4676	
2005	546	491	581			569					3050		528			3970	
2006	670	583	888			507					5999		665			2257	
2007	870	631	910			650							501			2786	
2008	1238	1120	1135			845					4282		401			4187	
2009	1449	714	1320			909					7306		382			4300	
2010	1364	1090	1798			982					4816		757			4654	

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A36 Nakhon Phanom Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	136	312				166		317	277								
1985	115	217				295		188									
1986	130	381				230		157									
1987	198	382				265	245	234									
1988	578	275				301		289									
1989	582	271	609			377	327	232									
1990	405	365	941			364	210	212									
1991	452	394	1030			409		312									
1992	453	377	812			427		327									
1993	434	282	504			363	157	275				4187					1339
1994	460	322	603			421	364	253		1566		4425					1298
1995	542	480	963			464		534	596	3815		4345					1671
1996	744	490	794			613		404		5144		4799	9				2362
1997	684	261	619			530		242		3280		2843	135				2264
1998	476	317	615			443				995		3897	282				2319
1999	459	230	760			380							313				1409
2000	385	184	631			381							535				1010
2001	334	216	650			442							510				966
2002	420	340	613			458							622				1973
2003	451	386	734			489							887				2086
2004	566	338	511			530							916			3543	1701
2005	585	451	583			549							817			4387	1479
2006	656	563	1020			516							922			2679	1367
2007	817	606	1037			636							883			3070	2513
2008	1110	1064	1228			860				3400			839			5006	2572
2009	1296	696	1401			870				2872			759			4025	2962
2010	1297	1048	1966			938				6479	2024		1305			4138	3735

Source Author’s calculations based upon data from Office of Agricultural Economic

Table A37 Mukdahan Province Gross Revenue by Crop ($/ha)

Year	PD	CV	SC	MZ	MB	GN	SB	KN	CT	GL	PT	SL	PR	DR	LG	OR	PA
1984	196	294				205		453	272								
1985	149	198				176		187	289								
1986	169	431				176		133	156								
1987	215	424				298		179									
1988	598	317				241	269	296									
1989	609	303	651			367	320	227	327								
1990	481	367	853			380	332	232	672								
1991	548	423	888			455		289									
1992	531	386	748			468		265	295								
1993	452	316	370			414	342	264	489								
1994	553	331	831			420	353	275	796								
1995	575	545	821			524		651	707								
1996	905	474	789			652		496	570								
1997	759	264	565			568		270	754								
1998	473	386	616			442		231	371								
1999	424	300	764			418		360	424				18				
2000	380	200	626			414		424					129				
2001	362	210	637			463		360					245				
2002	440	354	617			449		235					329				
2003	515	349	734			642		231					611				
2004	630	375	522			617		188					694				
2005	335	497	594			622		191	147				691				
2006	723	565	975			508		389	187				937				
2007	884	596	1012			713		348	349				865				
2008	1198	1052	1261			914		343					896				
2009	1380	751	1461			1005							631				
2010	1236	1149	2079			935							1585				

Source Author's calculations based upon data from Office of Agricultural Economic

Table A38 Observed monthly area-averaged precipitation (averaged over 1980-2009) by province (mm)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Jan	5.4	3.9	3.9	1.9	2.4	2.8	3.7	3.2	5.6	6.2	6.4	3.1	2.9	3.4	4.3	3.0	2.8
Feb	15.9	14.2	10.9	9.5	10.7	14.8	11.7	14.5	16.6	15.7	17.4	14.7	12.1	18.1	25.2	21.4	15.9
Mar	42.6	39.8	38.1	33.8	30.6	27.5	49.0	42.4	34.8	44.0	34.4	41.1	30.7	34.4	44.9	42.5	34.1
Apr	79.7	77.5	81.3	80.2	81.1	64.2	89.9	75.5	76.1	90.5	91.1	75.6	59.2	67.4	86.7	82.1	74.1
May	148.2	153.9	165.5	175.9	213.7	185.5	158.0	157.8	190.3	185.2	254.4	169.4	166.8	178.0	223.6	236.7	196.1
Jun	111.4	152.0	184.9	207.8	242.4	228.7	119.6	149.1	218.3	147.4	386.3	178.5	200.2	220.3	269.9	332.0	240.3
Jul	114.5	156.8	194.7	207.4	268.3	232.7	113.4	143.7	208.0	135.2	408.5	169.7	188.9	207.7	296.2	378.3	250.0
Aug	147.0	192.8	226.7	255.4	321.4	307.4	171.6	201.4	262.9	185.6	447.9	224.5	261.8	285.7	356.0	458.9	326.9
Sep	218.4	243.0	246.7	268.9	284.1	251.4	235.5	250.8	242.1	227.5	302.7	252.5	226.9	233.4	240.7	262.6	229.2
Oct	131.9	136.0	126.3	133.5	116.3	93.2	130.5	118.6	90.9	114.1	78.7	114.5	90.9	83.0	77.1	78.0	88.3
Nov	23.9	29.9	26.9	30.1	24.5	13.7	19.6	16.3	10.8	18.2	11.3	21.6	13.7	12.9	11.0	11.4	13.3
Dec	2.9	2.7	2.5	1.7	1.6	0.9	5.4	3.4	2.9	4.3	2.6	1.6	1.1	2.8	3.7	3.6	1.8

Source Author's calculations based upon data from Thai Meteorological Department

Table A39 Observed monthly area-averaged maximum temperature (averaged over 1980-2009) by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Jan	30.9	31.2	31.2	31.5	31.6	30.3	31.0	30.9	30.0	30.1	29.5	31.2	30.5	30.3	29.3	29.4	30.3
Feb	33.6	33.8	33.6	33.8	33.9	32.6	33.6	33.2	32.5	32.9	31.9	33.5	32.9	32.5	31.5	31.4	32.6
Mar	35.5	35.6	35.5	35.7	35.8	34.9	35.6	35.4	34.9	35.1	34.5	35.5	35.0	34.7	33.9	33.8	34.9
Apr	36.3	36.3	36.2	36.4	36.4	35.9	36.4	36.4	36.1	35.8	35.8	36.6	36.0	35.8	35.2	35.1	35.9
May	34.7	34.7	34.6	34.7	34.7	34.3	34.5	34.5	34.2	33.7	33.9	34.9	34.4	34.2	33.6	33.6	34.3
Jun	34.0	33.8	33.5	33.3	33.1	32.8	33.4	33.5	33.0	32.9	32.8	33.8	33.2	33.1	32.5	32.3	32.8
Jul	33.5	33.2	32.8	32.6	32.4	32.2	32.9	33.0	32.5	32.4	32.2	33.3	32.5	32.5	32.0	31.7	32.2
Aug	33.0	32.7	32.3	32.0	31.9	31.7	32.4	32.4	32.0	32.0	31.8	32.7	31.9	32.0	31.5	31.4	31.7
Sep	32.0	32.0	31.7	31.7	31.8	31.9	31.9	32.0	31.8	31.6	31.7	32.2	31.4	31.7	31.4	31.6	31.9
Oct	31.1	31.0	31.2	31.5	31.7	31.6	31.6	31.7	31.6	31.1	31.6	31.9	31.2	31.4	31.2	31.5	31.6
Nov	30.3	30.5	30.7	31.1	31.2	30.6	30.9	31.1	30.6	30.3	30.5	31.3	30.5	30.8	30.4	30.5	30.6
Dec	29.4	29.7	29.9	30.3	30.3	29.1	29.9	30.0	29.1	28.9	28.8	30.2	29.4	29.4	28.7	28.7	29.1

Source Author’s calculations based upon data from Thai Meteorological Department

Table A40 Observed monthly area-averaged minimum temperature (averaged over 1980-2009) by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Jan	18.1	17.6	17.9	17.6	17.4	16.4	18.4	17.3	16.3	14.9	16.7	17.0	17.3	16.8	16.4	16.3	16.4
Feb	20.7	20.2	20.5	20.2	19.9	19.2	20.7	19.9	18.7	17.0	19.1	19.8	20.0	19.6	19.1	19.1	19.2
Mar	23.0	22.6	23.0	22.8	22.6	22.3	23.0	22.6	21.6	20.0	21.9	22.6	22.8	22.5	22.1	22.0	22.3
Apr	24.7	24.4	24.9	24.6	24.5	24.6	24.8	24.7	24.1	22.7	24.3	24.7	24.8	24.6	24.5	24.3	24.6
May	24.9	24.6	24.9	24.7	24.5	24.8	24.9	24.7	24.5	23.6	24.7	24.8	24.9	24.8	24.8	24.7	24.8
Jun	24.9	24.7	24.9	24.6	24.4	25.0	24.8	24.9	24.9	24.2	24.9	24.9	25.1	25.1	25.1	24.9	25.0
Jul	24.5	24.3	24.6	24.4	24.2	24.7	24.5	24.6	24.7	24.0	24.8	24.6	24.9	24.8	24.9	24.7	24.7
Aug	24.4	24.2	24.5	24.2	24.0	24.5	24.2	24.3	24.5	23.8	24.5	24.4	24.7	24.6	24.6	24.5	24.5
Sep	24.0	23.9	24.2	23.9	23.6	24.0	24.0	23.9	24.0	23.1	24.1	23.9	24.3	24.1	24.2	24.0	24.0
Oct	23.2	23.0	23.2	22.8	22.5	22.5	23.4	22.8	22.7	21.8	22.8	22.8	23.0	22.8	22.7	22.5	22.5
Nov	20.8	20.6	20.7	20.4	20.2	19.6	21.1	20.2	19.6	18.5	19.7	20.0	20.3	19.8	19.5	19.4	19.6
Dec	18.0	17.7	18.0	17.8	17.6	16.5	18.3	17.1	16.2	14.9	16.3	16.9	17.3	16.7	16.1	16.1	16.5

Source Author's calculations based upon data from Thai Meteorological Department

Table A41 Area-averaged rainfall in summer season by province (mm)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	78.6	65.8	64.6	87.8	137.1	92.1	85.1	70.9	81.1	80.1	132.8	99.5	83.3	107.9	136.9	201.9	147.1
1985	124.1	130.4	164.6	124.5	149.1	74.5	95.7	63.0	62.1	84.6	112.5	77.0	67.9	46.4	88.7	63.5	62.0
1986	80.4	102.9	95.3	78.3	57.1	57.0	136.8	117.0	89.4	104.0	70.7	98.8	79.9	126.6	92.6	99.6	127.0
1987	62.4	57.3	33.6	53.9	53.0	40.9	105.9	89.3	82.9	93.9	77.8	86.3	38.2	49.2	68.0	65.9	39.8
1988	125.9	107.6	103.6	80.7	101.8	29.9	172.5	85.7	65.3	71.4	86.5	86.3	45.8	55.9	73.4	70.3	84.9
1989	42.5	39.5	52.4	59.3	75.8	42.0	57.8	61.2	86.6	124.3	85.6	51.1	37.0	55.4	85.7	100.6	65.0
1990	42.9	64.9	42.6	48.4	39.5	23.8	22.7	43.0	37.5	25.5	33.6	40.3	37.5	50.7	68.6	65.0	53.2
1991	36.8	41.4	40.7	65.4	31.7	23.5	57.8	44.3	44.1	108.8	26.0	21.5	21.7	16.4	30.8	16.9	13.6
1992	28.6	17.4	19.3	15.9	11.3	30.2	22.4	17.5	7.5	33.1	7.8	26.7	26.6	5.5	14.8	21.1	32.3
1993	89.4	85.3	107.8	96.7	93.5	110.7	89.5	54.0	42.9	77.7	71.6	77.0	83.0	73.5	72.0	84.1	85.4
1994	45.8	41.9	40.2	49.7	52.5	54.3	94.9	41.1	52.3	58.4	75.0	53.8	54.8	40.6	84.7	65.0	52.7
1995	65.8	63.3	50.6	39.2	48.7	57.1	40.1	55.5	72.8	67.5	61.0	52.5	61.3	53.7	58.6	45.5	46.2
1996	115.5	100.8	106.9	124.4	142.4	146.4	99.4	112.1	97.4	141.0	184.5	138.2	115.9	104.9	118.3	153.9	131.3
1997	86.5	71.0	99.7	104.2	114.5	71.7	86.4	87.1	82.1	104.7	137.3	67.6	48.6	78.0	127.8	132.8	98.1
1998	46.0	45.4	78.5	86.5	66.0	38.3	70.4	54.4	57.7	79.1	61.3	69.3	52.1	54.3	35.3	61.4	44.2
1999	175.4	171.3	185.0	131.2	153.3	73.8	172.9	155.7	176.0	154.0	207.7	159.1	128.0	104.4	126.8	71.6	79.7
2000	176.0	161.4	156.8	177.6	166.0	132.7	221.3	220.4	228.0	158.1	169.4	231.2	129.3	148.8	192.3	162.1	202.8
2001	43.2	27.9	28.6	22.6	37.1	28.6	52.5	44.5	46.8	58.6	32.2	50.1	35.0	43.9	50.2	41.2	38.6
2002	68.8	56.7	82.5	78.1	70.0	83.5	118.3	69.3	45.7	52.9	51.4	65.9	77.1	62.2	50.8	41.0	41.5
2003	78.6	84.8	52.6	77.1	50.5	35.6	82.1	49.9	50.9	45.1	75.4	53.6	35.8	36.6	48.9	63.2	52.6
2004	64.7	76.4	81.0	48.1	79.9	40.0	87.1	103.5	101.1	93.4	105.5	60.5	48.4	73.9	138.5	91.3	52.2
2005	75.7	88.7	94.9	89.1	70.2	68.8	73.4	73.2	48.5	43.9	68.4	59.7	68.7	49.5	101.1	102.9	72.9
2006	66.8	66.8	90.1	122.8	114.0	100.5	91.6	91.0	156.4	185.5	163.8	73.4	67.7	65.8	116.8	73.3	68.3
2007	79.9	98.1	81.9	66.8	54.8	48.2	63.3	43.2	30.3	101.2	64.8	38.3	36.9	26.3	35.1	62.0	31.2
2008	166.6	130.9	88.1	64.5	76.4	79.2	160.8	178.4	112.2	177.9	118.8	156.6	63.7	159.3	168.4	73.9	85.6
2009	116.1	81.5	136.9	138.1	141.4	78.2	87.2	66.0	89.0	106.5	48.6	63.3	47.6	75.2	81.9	54.1	108.0
2010	67.8	54.2	65.6	45.3	58.1	39.7	55.4	55.3	97.8	84.4	66.8	82.3	52.6	41.3	48.3	49.7	102.1

Source Author’s calculations based upon data from Thai Meteorological Department

Table A42 Area-averaged rainfall in rainy season by province (mm)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	115.6	183.6	252.1	308.0	524.7	327.0	90.3	131.9	244.6	132.5	478.5	185.2	220.6	272.6	426.6	682.3	334.3
1985	57.3	106.9	208.3	253.5	365.5	330.4	105.4	95.4	209.5	73.7	470.1	162.8	323.8	235.2	281.6	504.0	384.2
1986	162.7	227.3	253.6	267.6	388.4	296.9	137.6	159.3	219.7	111.7	406.2	169.3	225.2	293.8	415.3	514.1	364.5
1987	112.9	104.2	125.5	216.1	375.6	254.1	191.5	238.7	321.3	299.3	337.9	170.9	164.8	308.3	447.1	441.7	365.9
1988	97.5	116.3	107.6	170.7	217.2	215.2	114.6	92.8	172.8	135.9	428.4	119.1	99.8	186.1	350.7	589.7	362.7
1989	130.7	202.4	214.1	258.4	372.8	339.0	136.1	152.8	267.0	157.3	414.7	206.1	278.3	297.9	367.6	341.3	500.4
1990	118.4	186.6	199.2	216.9	325.0	336.1	79.1	170.6	298.0	199.1	364.3	218.8	317.9	381.7	488.2	502.2	415.1
1991	187.4	221.6	279.3	310.3	418.2	297.0	262.9	327.2	288.2	253.7	386.3	321.4	309.6	449.7	372.1	487.0	425.0
1992	184.9	257.4	297.7	286.1	442.3	371.1	180.3	137.2	285.8	174.3	421.2	192.2	265.9	287.2	425.4	414.9	343.0
1993	114.5	118.3	173.1	221.9	251.2	168.3	140.1	114.5	164.3	107.3	349.0	131.9	154.1	182.7	290.7	351.0	258.2
1994	136.2	190.4	256.9	351.0	343.8	422.1	254.6	129.0	232.1	208.5	549.1	212.6	325.5	344.8	390.5	523.4	503.1
1995	192.2	197.5	188.0	200.2	168.6	221.3	263.0	238.1	364.1	286.9	592.1	244.6	239.6	246.7	382.2	518.9	301.0
1996	145.8	146.8	169.0	183.0	222.2	212.8	179.7	110.2	230.1	203.6	362.8	192.0	156.7	184.9	287.7	460.0	334.4
1997	136.6	213.5	266.5	202.0	319.6	287.4	101.2	114.1	290.2	163.0	434.1	167.5	256.4	283.6	428.5	524.9	323.9
1998	193.7	208.2	171.3	281.6	307.5	224.2	276.2	276.2	207.6	174.5	261.8	264.6	221.3	224.5	234.6	207.3	196.0
1999	119.6	143.5	124.9	156.2	130.9	136.5	139.4	92.3	256.5	238.4	371.8	93.4	106.6	140.1	263.1	276.2	172.2
2000	247.3	306.2	362.4	416.4	306.2	330.6	249.7	258.6	210.6	157.2	400.4	270.2	311.8	219.3	238.8	347.7	213.6
2001	153.6	223.5	281.3	346.0	465.0	653.7	223.0	329.8	509.4	344.0	541.7	300.0	399.6	477.1	501.7	574.0	458.5
2002	199.7	318.1	333.6	325.2	365.4	573.7	229.3	276.7	356.5	268.6	542.3	368.4	380.7	379.3	369.6	451.1	427.5
2003	134.4	157.9	183.5	206.2	330.9	447.3	244.7	285.2	241.3	182.9	460.8	296.8	319.5	317.7	280.4	397.7	352.7
2004	119.4	208.6	257.3	222.3	283.8	225.3	126.7	256.1	230.5	153.8	480.2	208.6	288.1	308.8	285.6	462.2	207.9
2005	114.3	154.6	263.3	222.6	285.2	300.6	127.6	160.5	223.7	136.7	444.9	280.8	302.2	320.2	429.3	570.0	342.1
2006	163.8	205.0	253.4	331.6	366.4	265.6	187.5	284.8	380.2	264.7	497.8	212.2	333.4	292.7	381.8	513.2	307.7
2007	175.3	193.5	282.7	352.3	420.3	350.6	198.6	352.4	408.5	261.6	634.3	399.0	353.7	470.4	492.8	566.4	369.7
2008	162.5	199.2	175.4	243.0	257.3	134.7	192.0	376.7	250.6	145.9	426.4	262.5	165.0	338.7	310.1	424.5	170.2
2009	146.3	147.5	179.5	207.6	204.4	411.4	145.2	219.0	197.5	164.2	487.7	237.6	378.7	297.1	280.0	332.6	237.3
2010	240.3	238.7	271.2	262.9	354.6	566.0	249.4	435.3	596.1	488.3	435.0	375.6	244.6	512.1	676.0	458.3	570.0

Source Author’s calculations based upon data from Thai Meteorological Department

Table A43 Area-averaged rainfall in winter season by province (mm)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0
1986	4.0	3.1	3.4	2.0	3.0	1.7	2.1	10.6	22.6	16.4	12.9	1.1	0.8	1.5	3.8	2.2	2.2
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	1.4	0.3
1991	7.8	2.3	0.2	0.2	5.0	1.1	50.5	36.7	27.9	18.7	15.5	4.0	1.8	23.6	42.9	44.4	9.5
1992	16.1	15.5	8.4	8.6	2.8	12.6	3.8	11.2	12.2	22.7	8.9	18.7	18.8	34.3	33.3	42.7	20.2
1993	6.2	9.1	4.7	3.3	4.1	0.4	0.3	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.1	0.0	0.0
1994	4.4	2.0	2.6	2.7	4.8	0.4	3.5	13.1	9.5	27.8	13.5	0.3	0.0	0.2	1.2	0.5	0.0
1995	0.0	0.5	2.2	2.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.5
1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.3	0.0	3.0
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	2.0	2.5	1.0	1.0	6.7	1.5	0.3	0.5	0.0	0.7	0.1	3.1	2.3	2.9	1.0	0.9	1.7
1999	0.2	1.2	1.4	1.6	1.0	0.8	0.9	0.0	0.3	0.8	0.2	0.2	0.0	0.1	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	0.8	1.1	5.2	5.1	2.9	0.2	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.3	0.4	0.1
2002	31.0	26.7	35.2	10.8	12.7	1.9	31.0	12.8	7.1	17.2	12.9	10.7	4.3	4.5	15.4	5.5	0.2
2003	0.0	0.0	0.0	0.1	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0
2005	2.7	10.4	2.0	5.9	0.4	0.1	0.2	0.3	0.2	0.7	0.0	0.2	0.1	0.2	0.2	0.0	1.5
2006	0.2	1.2	4.4	1.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.1	1.3	0.2	0.0	2.1
2007	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.4
2008	2.3	3.1	2.8	1.9	1.1	3.7	17.9	5.3	0.4	0.1	0.0	1.7	1.9	4.6	3.2	6.1	10.7
2009	2.6	0.1	0.0	0.0	0.0	0.0	1.9	2.2	0.5	1.6	1.4	0.7	0.0	2.2	6.0	1.8	0.0
2010	6.9	0.5	0.1	0.6	3.8	1.0	7.3	3.4	2.9	39.6	1.3	0.4	0.1	1.4	2.1	0.0	4.4

Source Author's calculations based upon data from Thai Meteorological Department

Table A44 Area-averaged maximum temperature in summer season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	36.4	36.4	36.5	36.4	36.0	35.1	36.6	37.6	36.6	36.6	36.5	36.8	35.9	36.0	35.6	35.2	35.1
1985	35.3	35.4	35.5	35.2	35.0	34.9	35.7	35.8	35.5	35.4	35.7	35.8	35.1	35.0	34.2	34.0	34.9
1986	35.9	36.2	36.2	36.1	35.9	35.0	36.3	36.1	36.3	35.9	36.7	36.5	36.0	35.7	35.0	35.0	35.0
1987	37.0	37.1	37.3	37.4	37.2	35.9	36.0	35.8	35.9	35.5	35.8	36.8	36.5	36.0	35.3	35.5	35.9
1988	35.3	35.4	35.9	36.0	35.9	35.5	35.5	35.5	35.4	35.2	35.5	36.0	35.9	35.5	35.1	35.2	35.5
1989	37.5	37.4	37.2	36.5	36.0	35.8	38.0	37.1	36.9	36.2	36.3	37.0	37.2	36.6	36.2	35.3	35.8
1990	37.5	36.8	36.9	37.4	37.5	36.3	37.7	37.1	37.1	36.9	37.0	36.6	36.3	36.2	36.3	35.2	36.3
1991	36.5	37.0	37.1	37.7	37.9	37.4	36.4	37.0	36.3	36.4	36.3	37.2	37.1	36.9	36.6	36.5	37.4
1992	38.5	39.0	38.8	39.1	39.1	38.5	39.1	39.2	39.2	39.6	39.2	39.2	38.6	38.7	38.6	37.8	38.5
1993	35.6	36.0	35.3	36.1	36.4	35.8	35.5	36.6	36.7	35.7	36.5	36.2	35.6	35.7	35.4	35.2	35.8
1994	37.5	37.4	36.7	36.6	36.5	37.2	37.1	37.5	36.6	36.1	36.2	37.4	36.5	36.5	35.8	35.7	37.2
1995	37.0	37.0	37.0	36.7	36.5	37.2	37.3	37.6	37.7	37.1	37.2	37.8	37.0	37.2	36.9	36.7	37.2
1996	35.2	34.9	34.6	34.4	34.1	33.2	34.6	34.2	32.9	32.4	32.1	34.7	33.7	33.3	32.0	32.4	33.2
1997	34.6	34.7	34.6	34.4	34.4	34.9	34.6	34.6	34.2	33.3	33.5	35.1	34.6	34.1	33.0	33.2	34.9
1998	37.7	37.4	37.6	37.5	37.4	38.0	37.5	37.0	36.8	37.0	36.5	37.6	36.9	36.8	36.3	36.6	38.0
1999	34.5	33.7	33.8	34.0	34.3	35.4	34.8	34.2	34.2	34.0	33.8	34.8	34.0	34.1	33.5	33.9	35.4
2000	34.1	34.5	34.5	34.5	34.6	34.4	34.3	34.2	34.6	34.3	34.2	34.9	34.2	34.1	33.4	33.5	34.4
2001	38.0	37.4	37.5	38.0	38.3	38.2	38.5	38.7	39.0	39.0	37.9	38.8	37.8	38.1	38.0	37.6	38.2
2002	36.9	36.4	36.2	37.0	37.3	36.3	36.7	36.5	37.5	36.8	37.0	36.9	36.0	35.9	35.6	35.4	36.3
2003	36.7	36.6	35.8	36.1	36.5	37.2	36.6	36.6	36.8	37.1	36.2	37.4	36.4	36.7	36.3	36.4	37.2
2004	37.4	37.2	37.1	37.4	37.4	35.7	37.7	36.7	35.4	35.9	34.5	37.2	36.7	35.7	33.9	33.7	35.7
2005	36.6	36.2	36.2	36.9	37.2	35.7	36.8	36.5	37.2	36.8	36.9	36.7	35.9	35.9	35.4	34.7	35.7
2006	35.4	35.4	35.0	35.6	35.9	35.4	35.9	35.8	35.3	34.3	35.0	35.9	35.0	35.3	34.9	34.6	35.4
2007	36.1	36.4	36.2	36.5	36.6	36.7	36.2	36.1	36.1	35.2	36.1	36.6	35.8	35.8	35.3	34.9	36.7
2008	35.3	36.1	35.8	36.1	36.2	35.6	34.3	34.7	34.9	34.2	35.1	35.5	35.1	34.8	34.5	34.5	35.6
2009	34.8	35.2	35.2	35.2	35.3	35.7	35.1	35.5	35.1	33.7	35.2	35.9	35.3	35.4	34.9	34.9	35.7
2010	37.9	37.9	37.7	37.9	37.9	37.2	38.2	38.2	38.2	38.4	37.7	38.4	38.3	37.8	37.0	36.5	37.2

Source Author's calculations based upon data from Thai Meteorological Department

Table A45 Area-averaged maximum temperature in rainy season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	32.3	32.4	31.9	31.2	30.8	30.8	32.1	31.9	31.7	32.2	31.5	32.2	31.5	31.4	30.7	30.3	30.8
1985	32.7	32.4	31.9	31.7	31.5	30.9	32.3	32.1	31.6	31.9	31.6	32.2	31.4	31.6	31.2	31.0	30.9
1986	33.3	32.7	32.6	31.9	31.4	31.7	33.1	32.7	32.5	32.8	32.4	32.6	32.0	32.2	32.0	31.7	31.7
1987	33.5	33.3	33.2	32.9	32.5	32.1	33.0	32.8	32.1	32.3	32.1	33.2	32.7	32.5	32.1	32.2	32.1
1988	32.9	32.7	32.5	32.5	32.4	31.8	32.4	32.5	31.5	31.8	31.6	32.7	32.1	32.1	31.6	31.3	31.8
1989	33.3	33.1	32.4	32.1	31.7	31.4	32.6	32.4	32.0	32.4	32.0	32.4	31.8	31.9	31.8	31.6	31.4
1990	33.7	32.9	32.5	32.3	32.1	32.0	33.5	33.2	32.5	32.8	32.5	33.1	32.2	32.4	31.9	31.8	32.0
1991	32.0	32.0	31.5	31.2	31.0	30.9	31.0	31.4	31.1	31.0	31.3	32.0	31.2	31.3	31.0	30.7	30.9
1992	32.3	32.5	31.8	31.5	31.4	31.8	31.8	31.8	32.1	31.8	32.2	32.0	31.3	31.6	31.6	31.8	31.8
1993	32.5	32.3	31.7	31.7	31.6	31.3	32.1	32.4	32.0	32.4	31.4	32.6	31.4	31.8	31.3	30.9	31.3
1994	32.7	32.9	31.8	31.6	31.4	31.1	31.4	32.1	31.3	31.2	31.0	32.5	31.5	31.7	31.0	30.9	31.1
1995	32.6	32.6	32.1	32.3	32.3	32.0	31.5	32.1	31.4	30.8	30.9	32.6	31.8	31.8	31.0	31.3	32.0
1996	32.9	32.7	32.7	32.6	32.4	32.1	31.8	32.6	32.1	31.7	31.5	32.7	32.5	32.1	31.3	31.6	32.1
1997	33.3	32.9	32.1	32.0	31.9	31.5	32.4	32.9	32.3	32.3	31.8	33.0	31.8	32.1	31.4	31.0	31.5
1998	33.6	33.6	33.5	33.1	32.9	33.0	33.1	33.7	33.3	33.3	32.9	33.9	32.9	33.1	32.8	32.8	33.0
1999	33.0	32.5	32.2	32.0	31.9	32.1	32.3	32.2	32.0	31.7	31.4	32.9	31.8	32.0	31.4	31.4	32.1
2000	32.8	32.8	32.2	32.2	32.2	32.2	32.0	32.4	32.3	32.3	32.1	33.1	32.0	32.3	31.8	31.7	32.2
2001	32.7	32.6	31.9	31.7	31.6	31.6	32.1	31.9	32.2	32.0	32.0	32.7	31.6	31.8	31.3	31.3	31.6
2002	32.8	32.5	31.6	31.6	31.5	30.9	32.3	32.2	31.6	31.7	31.2	32.6	31.5	31.7	31.0	31.0	30.9
2003	33.5	33.6	33.1	32.8	32.5	32.2	33.1	32.8	32.7	32.4	32.5	33.5	32.6	32.6	32.2	31.8	32.2
2004	33.2	32.9	32.4	32.3	32.2	32.1	32.5	32.6	32.3	32.0	32.1	33.1	32.2	32.3	31.8	31.4	32.1
2005	33.8	33.0	32.3	32.1	31.8	31.5	32.7	32.4	31.6	31.3	31.5	32.8	31.8	31.8	31.0	30.4	31.5
2006	33.1	32.7	32.1	31.8	31.6	31.9	32.1	32.2	32.0	31.9	31.5	32.8	31.9	32.0	31.5	31.4	31.9
2007	33.1	32.7	32.3	32.1	31.9	32.1	32.5	32.1	32.1	31.8	32.2	32.6	32.0	31.9	31.6	31.2	32.1
2008	32.8	32.7	32.3	32.6	32.7	32.5	31.9	32.4	32.0	31.7	32.1	33.0	32.5	32.3	31.5	31.4	32.5
2009	34.0	33.6	32.8	32.8	32.8	32.6	33.1	33.4	32.8	32.7	32.8	33.9	32.8	33.0	32.3	32.2	32.6
2010	32.5	32.6	32.0	32.1	32.0	31.6	31.7	32.0	31.6	31.3	31.6	32.4	31.9	31.9	31.5	31.2	31.6

Source Author’s calculations based upon data from Thai Meteorological Department

Table A46 Area-averaged maximum temperature in winter season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	29.7	30.2	30.7	30.3	29.9	27.9	30.0	30.1	29.2	29.8	29.0	30.0	29.5	29.2	28.4	28.3	27.9
1985	28.9	29.7	30.1	29.9	29.7	27.9	29.5	29.8	28.7	28.9	28.5	29.7	29.1	29.1	28.4	28.5	27.9
1986	29.4	29.4	30.2	30.1	29.8	27.9	30.1	30.0	28.8	28.6	28.9	29.9	29.3	29.2	28.6	28.3	27.9
1987	26.8	27.0	27.9	28.4	28.4	26.7	27.4	27.9	27.3	27.4	27.2	27.8	27.6	27.4	27.0	27.1	26.7
1988	28.6	28.8	29.3	29.3	29.1	27.4	28.9	29.3	28.2	27.9	28.2	29.2	28.7	28.5	27.8	27.9	27.4
1989	29.9	30.3	30.6	30.8	30.9	30.3	30.0	30.4	29.4	29.2	29.3	30.3	30.1	29.7	29.0	29.0	30.3
1990	29.6	29.8	30.2	30.4	30.4	29.2	29.8	30.2	29.4	29.6	29.1	30.2	29.8	29.8	29.4	29.3	29.2
1991	29.4	29.9	30.0	30.5	30.6	28.9	29.3	29.4	28.7	28.8	28.8	29.8	29.3	29.1	28.6	28.6	28.9
1992	30.1	30.3	30.5	31.0	31.3	30.0	30.7	30.7	29.7	29.6	29.3	30.5	30.0	29.8	29.1	29.3	30.0
1993	28.7	29.0	29.2	29.4	29.5	28.5	29.4	29.8	28.8	28.7	28.4	29.9	28.8	29.0	28.2	28.0	28.5
1994	31.4	31.9	31.7	31.7	31.7	31.3	31.7	31.3	29.9	29.6	29.5	31.8	30.9	30.9	30.0	30.4	31.3
1995	28.7	28.6	28.7	29.2	29.5	28.8	29.4	29.7	28.7	28.5	28.2	29.7	28.5	28.9	28.3	28.3	28.8
1996	28.2	28.4	28.3	29.0	29.4	28.8	28.9	29.2	28.1	28.2	27.4	29.3	28.3	28.5	27.6	27.9	28.8
1997	32.8	32.7	32.5	33.0	33.3	32.4	33.2	32.9	31.8	32.1	31.0	33.0	32.1	32.0	31.0	31.2	32.4
1998	29.5	29.1	29.3	29.6	29.8	29.6	30.6	30.5	30.1	29.7	30.0	30.3	29.3	29.6	29.2	29.1	29.6
1999	26.5	26.6	26.8	27.2	27.5	26.9	27.3	27.2	26.4	26.1	26.1	27.7	26.7	26.8	26.0	26.0	26.9
2000	30.6	30.9	30.7	31.3	31.6	31.2	31.6	31.9	30.4	30.5	30.2	32.0	30.6	31.0	30.0	30.2	31.2
2001	30.0	29.8	29.5	30.1	30.4	29.9	30.8	30.3	29.7	29.6	29.4	30.8	29.3	29.8	29.1	29.5	29.9
2002	31.3	31.7	31.8	32.6	33.1	32.8	31.8	31.4	30.6	29.7	30.4	32.3	31.7	31.6	30.9	31.3	32.8
2003	29.8	29.7	29.6	30.4	30.9	29.9	30.2	29.8	29.0	29.1	28.7	30.4	29.6	29.5	28.6	28.6	29.9
2004	30.6	30.8	31.0	31.5	31.7	31.0	31.2	30.7	29.9	29.9	29.7	31.6	30.8	30.6	29.5	29.8	31.0
2005	28.5	28.7	29.0	29.6	29.8	28.8	29.2	29.4	28.7	28.5	28.7	30.1	28.8	29.1	28.3	28.4	28.8
2006	30.0	30.5	30.4	31.0	31.2	29.9	30.4	30.6	29.6	29.5	28.7	31.5	30.4	30.2	28.8	29.0	29.9
2007	31.4	31.7	31.9	32.4	32.6	31.2	31.3	31.6	30.8	30.2	31.0	32.2	31.6	31.4	30.5	30.3	31.2
2008	28.3	28.8	28.9	29.6	29.9	28.3	28.5	28.8	28.1	27.4	28.3	29.5	28.5	28.5	27.8	28.0	28.3
2009	31.5	32.1	31.9	32.4	32.6	30.6	31.1	31.3	30.5	29.9	30.4	31.7	31.4	31.1	30.3	30.3	30.6
2010	30.5	30.8	30.9	31.5	31.7	30.0	30.6	30.6	29.9	28.7	29.9	30.7	30.3	30.3	29.9	29.9	30.0

Source Author's calculations based upon data from Thai Meteorological Department

Table A47 Population density by province (persons/ha)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	1.0	1.2	1.4	1.3	0.9	1.2	0.7	1.4	1.0	0.4	1.0	1.6	1.4	1.2	0.9	1.0	0.6
1985	1.1	1.2	1.4	1.4	0.9	1.2	0.7	1.4	1.1	0.4	1.0	1.6	1.4	1.2	0.9	1.1	0.6
1986	1.1	1.3	1.5	1.4	0.9	1.2	0.8	1.5	1.1	0.5	1.1	1.6	1.4	1.2	0.9	1.1	0.6
1987	1.1	1.3	1.5	1.4	1.0	1.2	0.8	1.5	1.1	0.5	1.1	1.6	1.4	1.2	1.0	1.1	0.6
1988	1.1	1.4	1.5	1.5	1.0	1.2	0.8	1.5	1.1	0.5	1.2	1.7	1.4	1.3	1.0	1.1	0.7
1989	1.2	1.4	1.6	1.5	1.0	1.3	0.8	1.5	1.2	0.5	1.2	1.7	1.5	1.3	1.0	1.1	0.7
1990	1.2	1.4	1.6	1.5	1.0	1.3	0.8	1.5	1.2	0.5	1.2	1.7	1.5	1.3	1.0	1.2	0.7
1991	1.2	1.4	1.6	1.5	1.0	1.3	0.8	1.6	1.2	0.5	1.2	1.7	1.5	1.3	1.0	1.2	0.7
1992	1.2	1.4	1.7	1.5	1.0	1.3	0.9	1.5	1.2	0.5	1.1	1.6	1.5	1.3	1.1	1.2	0.7
1993	1.2	1.4	1.6	1.5	1.1	1.3	0.9	1.5	1.2	0.5	1.2	1.6	1.5	1.3	1.1	1.2	0.7
1994	1.2	1.4	1.6	1.6	1.1	1.3	0.8	1.5	1.2	0.5	1.2	1.7	1.5	1.4	1.1	1.2	0.7
1995	1.2	1.4	1.7	1.6	1.1	1.3	0.9	1.5	1.2	0.5	1.2	1.7	1.6	1.4	1.1	1.3	0.7
1996	1.2	1.4	1.7	1.6	1.1	1.3	0.9	1.5	1.3	0.5	1.2	1.7	1.6	1.4	1.1	1.3	0.7
1997	1.2	1.4	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.6	1.2	1.8	1.6	1.4	1.1	1.3	0.8
1998	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.6	1.2	1.8	1.6	1.4	1.1	1.3	0.8
1999	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.6	1.2	1.8	1.6	1.4	1.1	1.3	0.8
2000	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.6	1.2	1.8	1.6	1.4	1.1	1.3	0.8
2001	1.3	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.6	1.2	1.8	1.6	1.4	1.1	1.3	0.8
2002	1.3	1.5	1.7	1.7	1.1	1.3	0.9	1.6	1.3	0.6	1.2	1.8	1.6	1.4	1.2	1.3	0.8
2003	1.3	1.5	1.7	1.7	1.2	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.2	1.3	0.8
2004	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.1	1.3	0.8
2005	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.1	1.3	0.8
2006	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.2	1.3	0.8
2007	1.2	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.2	1.3	0.8
2008	1.3	1.5	1.7	1.6	1.1	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.2	1.3	0.8
2009	1.3	1.5	1.7	1.6	1.2	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.2	1.3	0.8
2010	1.3	1.5	1.7	1.6	1.2	1.3	0.9	1.6	1.3	0.5	1.2	1.8	1.6	1.4	1.2	1.3	0.8

Source Author’s calculations based upon data from the National Statistical Office of Thailand

Table A48 Irrigated land by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	2.0	2.1	2.7	3.8	1.3	4.1	1.0	2.0	0.9	1.2	2.7	5.3	8.2	10.0	3.9	3.2	1.0
1985	2.2	2.3	3.2	4.1	1.4	4.3	1.2	6.1	1.0	1.3	2.7	5.5	8.3	10.2	4.4	3.8	2.1
1986	2.4	2.6	3.2	4.4	1.6	4.4	1.3	6.2	1.1	1.4	2.9	5.6	8.4	10.2	5.2	4.0	2.2
1987	2.6	2.7	3.5	4.5	1.8	4.5	1.4	6.4	1.2	1.4	4.9	5.7	8.7	10.5	5.5	4.2	2.3
1988	2.8	2.8	3.6	4.6	1.9	4.6	1.4	6.7	1.3	1.5	5.0	6.0	8.9	10.6	5.8	4.3	2.7
1989	2.9	3.2	3.8	4.7	2.2	4.7	1.6	6.9	1.4	1.7	5.0	6.5	9.0	11.0	5.9	4.3	2.7
1990	3.0	3.6	4.0	4.8	2.3	4.8	1.8	7.4	1.7	2.1	5.1	7.3	9.4	11.3	6.1	4.6	2.8
1991	3.1	4.0	4.4	5.0	2.6	5.1	1.9	7.8	1.9	2.2	5.5	8.4	9.7	11.4	6.3	4.6	2.9
1992	3.2	4.5	4.9	5.4	2.7	5.8	2.4	8.1	2.2	2.3	5.5	8.9	9.8	11.6	6.5	5.1	2.9
1993	3.3	5.1	5.0	5.8	2.9	7.2	2.6	8.4	2.4	2.4	5.7	9.3	10.1	11.7	6.6	5.2	3.1
1994	3.5	5.8	5.2	6.1	3.0	7.4	2.8	8.7	2.5	2.6	5.8	10.3	10.5	11.9	6.7	5.2	3.2
1995	3.6	6.2	5.5	6.2	3.2	7.6	3.6	9.0	3.2	2.9	6.0	10.9	10.9	12.0	6.8	5.3	3.2
1996	4.0	6.4	5.8	6.2	3.4	7.7	4.3	9.2	3.3	3.0	6.1	11.4	10.9	12.1	6.8	5.3	3.3
1997	4.1	6.6	5.9	6.4	3.5	8.0	4.3	9.3	3.3	3.1	6.1	11.6	11.2	12.1	6.9	5.4	3.4
1998	4.3	6.9	6.3	6.6	3.7	8.0	4.6	9.5	3.4	3.1	6.1	11.6	11.2	12.2	7.0	5.4	3.5
1999	4.4	7.2	6.3	7.1	3.7	8.1	4.6	9.5	3.4	3.1	6.1	11.7	11.4	12.3	7.0	5.5	3.5
2000	4.4	7.7	6.3	7.6	3.8	8.1	4.6	9.5	3.4	3.1	6.2	11.7	11.4	12.7	7.4	5.5	3.8
2001	4.6	7.7	6.3	7.8	3.8	8.1	4.6	9.5	3.4	3.2	6.3	11.8	11.5	12.8	7.6	6.7	4.1
2002	4.8	7.8	6.4	7.9	4.0	8.3	4.6	9.5	3.5	3.2	6.3	11.9	11.5	13.0	7.7	6.8	4.2
2003	4.8	8.7	6.6	7.9	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.2	7.8	6.8	4.3
2004	4.8	9.0	6.6	8.1	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.4	7.8	6.9	4.3
2005	4.8	9.0	6.6	8.5	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3
2006	4.8	9.0	6.6	8.6	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3
2007	4.8	9.0	6.6	8.6	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3
2008	4.8	9.0	6.6	8.6	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3
2009	4.8	9.0	6.6	8.6	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3
2010	4.8	9.0	6.6	8.6	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3

Source Author’s calculations based upon the irrigation map developed by Royal Irrigation Department

Table A49 Literate population by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	99.8	99.8	99.8	99.7	99.7	99.7	99.7	99.9	99.8	99.4	99.6	99.7	99.7	99.7	99.6	99.4	99.5
1985	99.8	99.8	99.8	99.7	99.8	99.7	99.8	99.9	99.8	99.6	99.7	99.7	99.8	99.8	99.8	99.7	99.5
1986	99.7	99.8	99.8	99.7	99.9	99.7	99.7	99.7	99.6	99.4	99.6	99.7	99.8	99.7	99.6	99.7	99.4
1987	99.7	99.8	99.8	99.9	100.0	99.8	99.8	99.8	99.8	99.7	99.7	99.8	99.7	99.9	99.8	99.8	99.5
1988	99.9	99.8	99.8	99.8	99.8	99.8	99.7	99.8	99.8	99.6	99.7	99.7	99.9	99.8	99.8	99.7	99.7
1989	99.8	99.7	99.8	99.8	99.8	99.6	99.9	99.9	99.7	99.5	99.7	99.7	99.7	99.8	99.7	99.6	99.5
1990	99.8	99.8	99.9	99.7	99.9	99.7	99.7	99.8	99.8	99.7	99.7	99.8	99.8	99.8	99.7	99.8	99.6
1991	99.8	99.8	99.8	99.7	99.9	99.8	99.7	99.7	99.6	99.3	99.7	99.7	99.8	99.6	99.7	99.6	99.4
1992	99.7	99.7	99.8	99.8	99.7	99.6	99.8	99.8	99.8	99.6	99.9	99.7	99.7	99.6	99.7	99.6	99.5
1993	99.8	99.8	99.8	99.7	99.8	99.7	99.8	99.8	99.8	99.6	99.7	99.7	99.8	99.9	99.7	99.7	99.5
1994	99.8	99.6	99.7	99.5	99.8	99.5	99.6	99.5	99.6	99.2	99.3	99.7	99.7	99.7	99.6	99.5	99.5
1995	99.9	99.8	99.8	99.8	99.9	99.8	99.8	99.9	99.8	99.5	99.7	99.8	99.8	99.8	99.7	99.7	99.2
1996	99.8	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.8	99.8	99.7	99.8	99.9	99.8	99.7	99.7	99.8
1997	99.8	99.9	99.7	99.8	99.9	99.6	99.7	99.9	99.8	99.8	99.7	99.8	99.7	99.8	99.8	99.7	99.4
1998	99.8	99.8	99.9	99.8	99.8	99.7	99.7	99.9	99.7	99.5	99.7	99.7	99.7	99.7	99.7	99.6	99.6
1999	99.8	100.0	99.9	99.8	99.9	99.6	99.8	99.9	99.8	99.7	99.6	99.9	99.9	99.9	99.8	99.8	99.6
2000	99.7	99.8	99.7	99.8	99.9	99.7	99.6	99.8	99.6	99.5	99.8	99.7	99.8	99.8	99.9	99.7	99.5
2001	99.9	100.0	99.9	99.8	99.8	99.7	99.8	99.9	99.8	99.6	99.8	100.0	100.0	99.8	99.7	99.7	99.6
2002	99.2	98.8	98.8	98.5	99.5	99.7	98.6	99.4	99.4	98.3	99.1	99.5	99.6	99.2	99.6	99.3	97.2
2003	99.6	99.5	99.6	99.4	99.9	99.9	99.4	99.9	99.8	99.2	99.7	99.9	99.9	99.8	99.8	99.8	99.4
2004	99.8	99.6	99.7	99.7	99.9	100.0	99.7	99.9	99.8	99.5	99.8	99.9	99.9	99.9	99.9	99.7	99.6
2005	99.8	99.6	99.8	99.7	100.0	100.0	99.8	99.9	99.9	99.7	99.9	99.9	100.0	100.0	99.3	99.8	99.5
2006	99.8	99.7	99.7	99.8	100.0	100.0	99.8	99.9	99.9	99.5	99.9	99.9	100.0	99.9	99.7	99.8	99.5
2007	99.8	99.7	99.8	99.4	100.0	100.0	99.9	99.8	99.8	99.8	99.9	99.9	100.0	99.9	99.7	99.9	99.6
2008	100.0	100.0	100.0	99.9	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0
2009	99.9	99.8	99.9	99.6	100.0	100.0	99.9	99.9	99.9	99.8	99.9	100.0	100.0	99.9	100.0	99.9	99.8
2010	99.9	99.8	99.9	99.8	100.0	100.0	99.9	99.9	100.0	99.8	99.9	100.0	100.0	100.0	100.0	100.0	99.7

Source Author’s calculations based upon data from Community Development Department

Table A50 Household own bullocks by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	25.3	78.7	83.4	90.9	83.4	99.3	25.8	54.8	56.1	15.2	46.7	80.9	83.0	56.5	75.5	79.0	83.0
1985	25.2	75.8	80.5	89.2	83.1	99.3	25.5	54.7	55.8	15.2	46.4	79.7	82.2	55.6	75.1	78.2	82.8
1986	25.1	70.6	80.5	89.0	82.9	96.7	25.4	54.5	55.3	15.2	46.4	78.0	81.3	55.5	74.6	77.5	82.5
1987	25.0	70.5	79.9	88.6	82.2	96.4	25.0	54.1	55.3	15.1	45.8	76.5	80.8	55.3	73.9	77.1	80.9
1988	24.7	69.4	79.9	87.6	82.2	91.8	24.9	53.8	55.0	14.7	45.8	76.4	80.7	55.0	73.8	76.6	80.8
1989	24.1	69.4	79.2	86.5	82.1	91.2	24.5	53.0	54.5	14.6	45.3	76.3	80.6	54.3	73.3	76.4	79.1
1990	24.0	68.7	77.4	86.4	82.0	85.9	24.0	52.8	54.5	14.6	44.8	73.2	80.3	54.2	72.3	76.0	78.8
1991	22.9	66.5	77.1	83.7	80.8	85.5	21.0	48.6	53.5	11.6	43.4	72.1	77.5	50.4	69.4	73.8	78.7
1992	21.7	64.8	76.8	81.4	82.1	84.6	18.2	45.1	52.3	8.7	41.9	70.5	74.8	46.3	65.8	71.8	78.6
1993	19.3	62.4	74.7	80.3	79.6	82.0	15.8	40.7	51.1	7.8	37.0	65.5	70.3	42.3	63.2	69.3	76.6
1994	16.6	60.2	72.6	79.2	78.4	80.4	13.2	36.5	49.9	7.0	32.9	61.3	67.2	38.3	60.7	66.9	74.6
1995	12.7	53.9	66.0	73.8	73.3	72.9	10.6	29.7	43.4	6.0	27.3	55.1	60.3	33.1	53.6	59.8	66.8
1996	9.0	47.3	59.4	68.5	68.8	65.4	7.8	22.9	37.0	4.8	22.0	49.1	52.9	26.0	46.6	52.8	59.0
1997	7.3	37.8	50.2	59.5	60.9	55.8	6.8	18.3	31.6	3.6	16.6	41.1	44.2	21.4	37.7	44.0	50.2
1998	5.5	27.6	41.2	49.5	52.8	46.4	6.3	13.5	26.6	2.9	11.6	33.4	35.5	16.7	28.9	33.4	42.4
1999	4.1	18.3	31.9	40.1	44.9	36.9	1.3	9.1	20.9	1.8	6.4	25.6	26.5	12.5	19.9	23.6	34.1
2000	2.9	15.3	27.9	36.9	41.5	33.2	5.2	8.8	17.3	2.8	5.3	20.3	22.5	11.3	17.1	20.0	29.3
2001	2.4	12.2	23.9	33.6	37.9	29.9	1.6	7.1	13.6	2.6	2.9	15.4	19.4	8.2	14.2	16.5	24.0
2002	2.3	11.6	20.2	27.5	32.2	25.7	4.6	6.5	12.1	2.6	4.5	15.4	15.3	7.4	10.6	13.7	22.2
2003	2.1	11.0	16.1	21.1	28.0	21.0	1.7	6.1	10.7	1.4	4.0	14.7	11.4	6.5	6.9	10.9	20.7
2004	2.0	10.0	14.7	18.8	24.6	17.6	3.7	5.8	9.8	2.4	3.8	12.7	10.1	6.1	6.6	10.1	18.1
2005	1.9	8.7	13.9	16.2	21.5	14.3	1.3	4.8	8.9	1.4	2.9	10.8	9.2	6.0	6.2	9.2	15.4
2006	1.5	7.2	11.3	14.8	19.7	10.9	2.6	5.3	8.0	2.3	2.6	9.1	8.2	4.8	5.6	7.9	13.3
2007	1.3	6.1	9.2	12.1	16.7	7.5	1.8	5.1	6.9	2.1	2.3	7.5	7.3	3.4	5.0	6.2	10.8
2008	1.3	6.3	9.2	11.3	14.7	7.3	1.6	4.4	5.8	2.0	2.1	7.2	6.7	3.1	4.3	5.9	8.3
2009	1.2	6.1	9.3	10.0	12.3	7.3	1.5	3.7	5.5	1.7	2.1	7.1	6.5	3.8	3.8	6.6	5.8
2010	1.1	6.0	8.7	8.4	11.8	6.8	1.4	3.6	5.5	1.2	1.2	7.0	6.4	3.1	3.2	5.7	5.2

Source Author’s calculations based upon data from Community Development Department

Table A51 Household own tractors by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	16.5	0.5	3.3	2.5	0.6	3.4	17.3	9.0	6.1	16.0	9.9	0.9	3.5	5.9	6.2	3.2	1.7
1985	16.5	0.7	3.5	2.7	0.9	4.3	17.3	9.8	6.7	16.0	10.0	0.9	4.0	6.5	6.3	3.3	1.8
1986	16.9	1.9	3.8	3.1	0.9	4.4	17.3	9.9	6.9	16.5	10.2	1.1	4.2	6.8	6.3	3.4	2.0
1987	16.9	3.0	4.3	3.3	1.1	4.6	17.3	10.0	7.4	17.0	10.3	1.1	4.3	7.6	6.3	3.8	2.2
1988	16.9	3.5	5.1	3.3	1.3	4.8	17.3	10.8	7.6	17.1	10.6	4.2	4.7	8.4	6.4	4.0	2.6
1989	17.0	4.6	5.5	3.4	1.3	5.0	17.3	12.6	8.0	17.1	10.8	4.7	4.7	10.7	6.4	4.0	3.1
1990	17.1	5.4	5.5	3.6	1.4	5.0	17.6	12.6	8.7	17.2	10.8	6.7	4.8	11.1	6.7	4.2	3.3
1991	18.7	6.2	5.8	5.3	2.5	6.0	19.7	15.2	10.2	19.2	12.6	8.6	6.5	13.8	8.1	5.1	4.4
1992	20.5	7.5	6.0	6.9	3.4	6.8	22.3	17.4	11.6	21.3	14.5	10.0	9.1	16.6	9.7	6.8	5.8
1993	21.2	8.8	7.3	8.6	5.2	8.9	24.5	19.4	12.9	22.2	16.6	12.0	11.3	18.6	11.1	8.7	7.2
1994	21.9	10.3	10.0	10.1	6.9	10.1	26.7	21.3	14.1	22.8	18.5	13.8	13.3	20.5	13.2	10.6	8.5
1995	24.3	13.2	12.5	13.3	9.5	13.6	24.5	24.2	17.1	25.9	21.7	17.3	17.1	24.1	16.2	12.5	11.6
1996	26.7	16.0	15.1	16.5	12.2	16.2	29.5	27.2	20.0	28.9	25.1	20.9	21.1	27.8	19.4	14.3	14.8
1997	26.9	19.3	18.4	20.5	15.3	19.8	32.2	29.0	23.6	30.5	28.7	22.7	23.8	29.8	22.9	17.6	16.7
1998	27.2	22.7	21.8	24.2	18.5	23.5	34.9	30.7	27.2	32.3	32.3	24.4	26.5	31.9	26.4	20.8	19.0
1999	26.7	26.1	25.1	28.3	21.7	27.2	37.5	32.6	30.7	34.0	36.1	26.1	29.4	33.9	29.8	24.0	21.2
2000	27.3	28.7	28.1	31.1	26.7	29.1	37.5	35.6	33.8	36.6	37.1	30.3	30.9	35.9	33.7	26.7	23.5
2001	28.0	31.4	37.1	33.7	31.6	31.1	37.6	38.3	37.0	38.8	40.8	34.5	32.6	38.1	37.8	29.4	26.1
2002	28.4	33.5	30.5	34.5	33.7	34.2	39.3	38.6	39.1	38.9	38.1	35.3	34.1	39.5	39.0	32.1	28.7
2003	29.7	35.8	33.9	37.8	35.7	37.0	40.8	38.9	41.2	39.1	38.8	36.3	35.6	40.9	40.3	34.6	31.5
2004	29.2	35.9	34.2	35.2	37.8	37.5	41.1	40.0	42.3	40.1	39.0	37.1	37.0	41.0	41.6	35.1	32.8
2005	29.4	34.7	34.2	37.7	40.0	38.1	41.5	38.7	43.5	41.1	39.7	37.7	38.2	41.1	43.0	35.5	31.7
2006	29.5	36.0	34.5	35.9	42.1	39.1	41.6	41.1	44.1	41.9	39.5	38.2	38.0	43.3	43.8	38.0	32.9
2007	28.8	33.7	35.1	36.7	43.4	40.8	40.5	42.1	43.0	32.2	39.5	40.5	35.9	45.1	44.7	32.1	34.0
2008	29.6	36.0	35.1	39.6	44.5	40.9	41.8	42.2	45.0	42.7	39.6	39.1	38.3	45.1	46.2	40.4	34.8
2009	27.9	33.3	35.0	42.6	46.2	37.9	41.5	38.9	45.6	43.6	39.7	35.8	38.2	40.3	47.6	42.8	35.7
2010	29.8	36.5	35.6	42.8	47.1	41.2	42.0	42.2	45.8	43.8	39.9	40.8	38.5	45.8	48.2	43.4	36.0

Source Author's calculations based upon data from Community Development Department

Table A52 Household own cultivators by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	1.3	0.1	0.0	0.1	0.1	0.1	0.6	0.2	0.2	1.5	0.3	0.0	0.3	0.0	0.1	0.0	0.2
1985	1.3	0.2	0.0	0.1	0.1	0.1	0.6	0.2	0.3	1.5	0.3	0.0	0.3	0.0	0.2	0.0	0.2
1986	1.3	0.2	0.0	0.1	0.1	0.1	0.6	0.2	0.3	1.5	0.3	0.0	0.3	0.1	0.2	0.1	0.2
1987	1.3	0.2	0.1	0.1	0.1	0.1	0.6	0.2	0.3	1.5	0.3	0.0	0.3	0.1	0.2	0.1	0.2
1988	1.3	0.2	0.1	0.2	0.1	0.1	0.6	0.2	0.3	1.5	0.3	0.1	0.3	0.1	0.2	0.1	0.3
1989	1.3	0.2	0.1	0.2	0.1	0.1	0.7	0.2	0.3	1.6	0.3	0.1	0.4	0.1	0.2	0.1	0.3
1990	2.0	0.2	0.1	0.2	0.1	0.1	1.0	0.2	0.3	1.6	0.3	0.1	0.4	0.1	0.2	0.1	0.3
1991	1.3	0.3	0.1	0.2	0.2	0.2	0.7	0.3	0.3	1.6	0.4	0.1	0.4	0.2	0.2	0.1	0.3
1992	1.3	0.2	0.1	0.3	0.2	0.2	0.7	0.4	0.4	1.6	0.4	0.1	0.5	0.2	0.3	0.3	0.3
1993	1.4	0.3	0.1	0.3	0.2	0.2	0.7	0.4	0.4	1.6	0.5	0.2	0.4	0.3	0.3	0.1	0.3
1994	1.4	0.3	0.1	0.3	0.2	0.2	0.8	0.3	0.4	1.6	0.6	0.2	0.5	0.4	0.3	0.1	0.4
1995	1.5	0.4	0.2	0.3	0.3	0.4	0.9	0.5	0.5	1.6	0.7	0.3	0.5	0.4	0.4	0.2	0.4
1996	1.5	0.5	0.2	0.3	0.4	0.5	1.1	0.6	0.7	1.7	0.7	0.3	0.4	0.5	0.3	0.5	0.5
1997	1.7	0.6	0.2	0.5	0.5	0.7	1.2	0.6	0.7	1.8	0.7	0.3	0.6	0.5	0.5	0.2	0.6
1998	1.9	0.7	0.3	0.7	0.6	0.9	1.4	0.6	0.8	1.9	0.8	0.3	0.6	0.6	0.6	0.2	0.8
1999	2.8	0.8	0.3	0.9	0.8	1.1	1.6	0.6	0.8	2.0	0.7	0.3	0.7	0.7	0.7	0.3	0.9
2000	2.0	0.8	0.4	1.0	1.0	1.3	1.6	0.8	1.0	2.1	0.8	0.5	0.7	1.0	0.7	0.4	0.8
2001	2.2	0.9	0.5	1.0	1.2	1.0	1.3	0.9	1.1	2.1	0.8	0.5	0.8	1.2	0.7	0.5	0.8
2002	2.1	1.0	0.6	1.0	1.3	1.5	1.7	1.2	1.2	2.4	0.9	0.6	0.8	1.5	0.8	0.6	0.9
2003	2.2	1.0	0.7	1.1	0.9	1.1	1.8	1.5	1.4	2.7	0.9	0.8	0.9	2.2	0.8	0.8	1.1
2004	2.2	1.1	0.8	1.3	1.4	1.7	1.9	1.5	1.5	2.9	1.3	1.0	0.9	1.7	0.8	0.9	1.2
2005	2.3	1.1	0.9	1.5	1.1	2.0	2.1	1.4	1.5	3.1	0.8	0.7	1.0	2.0	0.9	0.9	1.9
2006	2.5	1.4	1.3	1.7	1.5	2.0	2.1	1.6	1.6	2.5	1.6	1.2	1.2	2.0	1.1	0.9	1.4
2007	2.8	1.7	1.8	1.8	1.7	1.7	2.1	1.7	1.7	2.0	1.9	1.4	1.3	2.0	1.3	0.9	1.5
2008	3.0	2.0	2.0	1.9	1.7	2.0	2.3	1.7	2.2	2.5	2.1	1.7	1.9	2.0	1.3	1.2	1.7
2009	3.2	2.3	2.2	1.9	1.9	2.0	2.5	1.4	2.8	2.8	2.3	2.1	2.4	1.6	1.2	1.5	1.7
2010	3.2	2.3	2.3	2.0	1.9	2.0	2.6	1.7	2.8	2.9	2.3	2.1	2.4	2.0	1.3	1.5	1.7

Source Author’s calculations based upon data from Community Development Department

Table A53 Soil order areas by province (%)

Soil	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Alfisols	35.1	18.0	15.9	25.5	24.6	15.3	38.2	63.8	15.8	68.4	7.8	39.7	37.1	12.1	9.4	11.9	19.0
Inceptisols	9.0	6.3	16.6	26.2	8.4	16.1	3.0	1.6	1.3	0.0	8.5	7.8	25.2	13.5	3.5	1.0	0.9
Oxisols	5.6	0.9	0.0	2.1	0.3	0.0	1.5	1.3	1.9	15.1	1.1	0.0	0.0	0.0	0.0	0.1	0.1
Ultisols	32.3	58.1	52.9	37.5	49.1	59.0	42.7	13.0	68.8	12.5	70.5	39.6	28.6	60.1	78.0	76.7	74.7
Vertisols	5.4	3.0	0.7	0.5	1.0	1.7	5.8	2.8	1.5	0.3	1.4	0.1	0.2	0.0	0.0	0.5	0.1

Source Author's calculations based upon the soil map for Thailand developed by Land Development Department

Table A54 Projected annual area-averaged climate by province

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Rainfall (mm)																	
A2																	
2020s	1200.9	1268.9	1428.2	1500.9	1879.1	1586.6	1288.3	1278.8	1531.0	1567.0	2207.7	1282.7	1458.7	1480.9	1748.1	1967.9	1667.2
2050s	1216.7	1290.7	1467.6	1528.9	1936.2	1676.6	1340.6	1354.4	1698.0	1658.2	2457.5	1346.5	1544.3	1614.2	1996.0	2274.3	1822.3
2080s	1357.2	1402.9	1556.1	1602.5	2093.0	1781.8	1485.3	1448.9	1823.7	1775.7	2665.0	1430.8	1623.1	1694.9	2118.4	2424.4	1894.0
B2																	
2020s	1205.6	1278.3	1415.9	1464.7	1820.8	1563.1	1313.7	1310.4	1578.6	1608.8	2251.0	1283.0	1443.5	1507.7	1763.9	1980.6	1653.8
2050s	1222.4	1282.3	1415.9	1467.9	1875.4	1615.4	1338.3	1333.2	1643.7	1674.9	2422.6	1298.1	1479.3	1540.3	1869.3	2113.4	1698.4
2080s	1254.4	1341.1	1510.9	1567.9	1966.0	1695.1	1376.8	1374.0	1661.7	1674.8	2406.5	1365.3	1558.2	1598.7	1897.5	2160.8	1787.6
Maximum Temperature (°C)																	
A2																	
2020s	32.9	33.2	33.3	33.3	33.1	32.5	32.6	32.9	32.5	31.3	32.3	33.1	32.7	32.3	32.1	32.2	31.7
2050s	34.0	34.3	34.5	34.5	34.2	33.7	33.8	34.0	33.6	32.4	33.5	34.3	33.8	33.5	33.2	33.2	32.8
2080s	35.3	35.7	35.9	35.9	35.7	35.0	35.1	35.4	35.0	33.7	34.9	35.6	35.2	34.7	34.6	34.5	34.1
B2																	
2020s	32.9	33.2	33.4	33.4	33.1	32.6	32.6	32.8	32.4	31.2	32.3	33.1	32.7	32.4	32.1	32.1	31.7
2050s	33.7	34.1	34.2	34.2	34.0	33.4	33.4	33.7	33.3	32.1	33.2	33.9	33.5	33.2	33.0	33.0	32.5
2080s	34.5	34.9	35.1	35.1	34.8	34.2	34.3	34.6	34.3	33.0	34.2	34.8	34.4	34.0	33.9	33.9	33.4
Minimum Temperature (°C)																	
A2																	
2020s	22.1	22.6	23.3	23.6	23.4	22.6	21.7	22.1	21.5	20.2	21.4	22.6	22.6	21.8	21.4	21.7	21.5
2050s	23.4	23.9	24.6	24.9	24.7	23.9	23.0	23.4	22.9	21.6	22.7	23.9	23.8	23.1	22.7	22.9	22.7
2080s	25.0	25.5	26.2	26.5	26.2	25.4	24.6	24.9	24.4	23.2	24.2	25.4	25.3	24.6	24.1	24.4	24.2
B2																	
2020s	22.1	22.7	23.3	23.7	23.5	22.7	21.7	22.1	21.5	20.2	21.4	22.6	22.6	21.9	21.4	21.7	21.6
2050s	23.1	23.6	24.3	24.6	24.4	23.6	22.7	23.1	22.5	21.2	22.4	23.6	23.5	22.8	22.4	22.6	22.5
2080s	24.0	24.5	25.2	25.5	25.3	24.5	23.6	24.0	23.5	22.2	23.4	24.5	24.4	23.7	23.3	23.6	23.4

Source Author's calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A55 Projected area-averaged rainfall in each season by province (mm)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Summer																	
A2																	
2020s	81.9	100.5	100.0	102.5	103.2	100.0	67.6	62.1	70.2	65.6	100.9	82.5	98.3	93.3	97.3	102.0	100.0
2050s	87.4	101.4	107.9	113.4	117.4	101.9	70.1	94.2	88.5	68.0	114.2	100.0	100.0	103.1	107.3	135.3	104.9
2080s	101.4	106.0	131.0	127.8	137.2	114.3	96.4	100.0	106.4	97.5	146.4	100.0	100.0	107.3	138.6	152.3	130.7
B2																	
2020s	65.4	93.6	99.5	100.0	100.4	94.8	50.5	50.0	54.2	49.7	82.1	52.2	79.1	68.9	91.9	100.0	100.0
2050s	83.2	100.1	100.0	101.7	102.2	98.8	65.5	57.8	59.7	57.4	101.8	72.5	93.0	82.4	96.3	104.0	100.0
2080s	87.9	100.3	100.2	103.7	102.7	99.5	82.1	85.9	87.5	69.0	106.0	90.8	96.2	95.5	97.7	105.0	100.0
Rainy																	
A2																	
2020s	206.8	240.9	288.0	307.7	378.3	347.4	241.9	264.1	310.7	273.5	473.6	272.0	301.9	319.4	381.3	433.5	356.5
2050s	204.0	229.4	276.3	306.6	373.1	360.4	248.5	277.1	357.2	291.0	534.7	289.2	324.6	367.5	440.6	503.9	392.0
2080s	194.7	228.6	279.6	308.5	405.8	368.5	236.4	273.8	363.2	288.0	559.5	289.4	322.6	361.1	467.8	552.7	405.5
B2																	
2020s	185.9	223.5	260.4	288.7	335.8	316.9	218.8	261.0	314.8	263.9	481.3	257.0	289.4	334.6	388.8	441.3	362.5
2050s	188.6	222.9	252.2	279.3	340.5	315.3	221.0	254.2	326.4	285.7	505.9	251.0	278.0	312.0	393.1	441.4	345.3
2080s	182.8	218.4	267.4	295.8	375.6	352.4	224.0	267.3	327.2	285.5	504.1	262.9	301.3	339.0	415.5	492.3	386.4
Winter																	
A2																	
2020s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2050s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2080s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B2																	
2020s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2050s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2080s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A56 Projected area-averaged maximum temperature in each season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Summer																	
A2																	
2020s	37.1	37.1	37.2	37.1	37.2	37.5	37.8	38.3	38.8	37.5	38.7	38.4	37.3	37.8	37.8	37.6	37.9
2050s	38.1	37.8	37.8	37.8	38.0	38.1	38.9	39.3	39.7	38.6	39.4	39.3	38.0	38.6	38.5	38.3	38.5
2080s	38.6	38.6	38.7	38.9	39.2	39.0	39.3	39.7	40.0	38.9	39.8	39.8	38.8	39.1	39.1	39.0	39.4
B2																	
2020s	37.8	37.8	38.0	37.9	38.0	38.3	38.6	39.1	39.6	38.3	39.5	39.3	38.2	38.6	38.6	38.5	38.7
2050s	37.9	37.8	37.9	37.9	38.2	38.3	38.8	39.3	39.8	38.5	39.5	39.3	38.1	38.7	38.7	38.5	38.9
2080s	38.8	38.8	38.9	38.9	39.2	39.4	39.5	40.1	40.6	39.3	40.4	40.2	39.1	39.6	39.6	39.5	39.9
Rainy																	
A2																	
2020s	31.8	31.9	30.7	30.1	29.5	29.4	30.9	30.4	30.3	29.8	29.9	30.4	29.4	28.9	28.8	28.9	29.0
2050s	32.8	32.9	31.8	31.3	30.7	30.6	31.8	31.4	31.2	30.5	30.7	31.5	30.5	30.0	29.9	29.9	30.2
2080s	34.7	35.0	34.0	33.4	32.4	32.6	33.8	33.5	33.3	32.5	32.6	33.7	32.6	31.9	31.7	31.6	32.0
B2																	
2020s	32.2	32.4	31.2	30.5	29.9	29.7	31.2	30.6	30.3	29.8	29.9	30.7	29.8	29.1	28.9	28.9	29.2
2050s	33.4	33.5	32.4	31.7	31.1	31.0	32.3	31.8	31.5	30.8	31.0	31.9	31.0	30.3	30.1	30.1	30.5
2080s	34.0	34.2	33.2	32.6	31.8	31.8	33.1	32.7	32.5	31.7	32.0	32.8	31.8	31.1	31.0	30.9	31.2
Winter																	
A2																	
2020s	29.5	30.6	32.4	33.0	32.6	31.9	28.9	30.1	27.9	26.5	27.7	31.7	31.4	30.9	29.4	29.3	31.1
2050s	30.5	31.7	33.5	34.1	33.9	33.0	29.9	31.1	29.1	27.5	29.0	32.8	32.5	31.9	30.5	30.4	32.2
2080s	31.9	33.1	34.9	35.6	35.4	34.5	31.5	32.7	30.9	29.2	30.9	34.3	33.9	33.4	32.1	32.0	33.8
B2																	
2020s	29.2	30.2	32.1	32.6	32.3	31.6	28.5	29.8	27.5	26.1	27.4	31.5	31.2	30.6	29.0	29.0	30.8
2050s	30.0	31.1	32.9	33.5	33.2	32.4	29.4	30.6	28.4	26.9	28.3	32.3	32.0	31.4	29.9	29.8	31.7
2080s	30.9	32.0	33.8	34.4	34.1	33.3	30.3	31.6	29.6	28.0	29.5	33.2	32.9	32.3	30.9	30.9	32.6

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A57 Projected area-averaged minimum temperature in each season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Summer																	
A2																	
2020s	25.0	25.4	26.1	26.5	26.5	26.0	25.0	25.9	25.8	24.1	25.5	26.2	26.1	25.7	25.8	25.9	25.2
2050s	26.4	26.7	27.3	27.6	27.6	27.2	26.6	27.3	27.2	25.5	26.7	27.5	27.2	26.9	26.9	26.9	26.3
2080s	27.5	27.9	28.6	28.9	28.7	28.2	27.5	28.2	28.0	26.6	27.6	28.5	28.3	27.8	27.7	27.7	27.2
B2																	
2020s	25.4	25.9	26.6	27.0	27.1	26.7	25.5	26.5	26.5	24.6	26.2	26.8	26.7	26.4	26.6	26.7	26.0
2050s	26.0	26.4	27.1	27.4	27.5	27.0	26.1	27.1	27.0	25.2	26.6	27.2	27.0	26.8	26.8	26.9	26.3
2080s	27.0	27.4	28.1	28.5	28.5	28.1	27.1	28.0	27.9	26.1	27.6	28.2	28.1	27.8	27.8	27.9	27.3
Rainy																	
A2																	
2020s	23.3	23.7	24.1	24.3	24.2	23.6	23.0	23.5	23.6	22.4	23.8	23.7	23.6	23.1	23.3	23.4	22.9
2050s	24.4	24.8	25.2	25.4	25.3	24.7	24.1	24.6	24.8	23.6	24.8	24.8	24.7	24.2	24.4	24.5	24.0
2080s	26.1	26.5	26.9	27.1	26.8	26.3	25.6	26.2	26.3	25.2	26.3	26.4	26.3	25.7	25.9	26.0	25.5
B2																	
2020s	23.4	23.9	24.3	24.5	24.4	23.8	23.1	23.6	23.7	22.5	23.8	23.9	23.8	23.3	23.4	23.6	23.1
2050s	24.4	24.8	25.2	25.4	25.3	24.7	24.0	24.5	24.7	23.4	24.7	24.8	24.7	24.2	24.3	24.5	24.0
2080s	25.2	25.6	26.0	26.2	26.0	25.5	24.8	25.3	25.5	24.3	25.5	25.6	25.5	24.9	25.1	25.3	24.7
Winter																	
A2																	
2020s	17.8	18.6	19.5	20.0	19.5	18.3	17.0	17.0	15.0	13.9	14.9	18.1	18.2	16.9	15.4	16.0	16.6
2050s	19.4	20.2	21.1	21.6	21.2	19.8	18.6	18.5	16.7	15.5	16.6	19.6	19.7	18.4	17.0	17.5	18.1
2080s	21.1	21.9	22.8	23.3	22.9	21.4	20.3	20.3	18.5	17.3	18.5	21.3	21.4	20.1	18.7	19.2	19.8
B2																	
2020s	17.5	18.3	19.2	19.7	19.3	17.9	16.6	16.6	14.6	13.6	14.6	17.7	17.8	16.5	15.0	15.6	16.3
2050s	18.5	19.3	20.2	20.7	20.3	19.0	17.6	17.6	15.6	14.5	15.6	18.7	18.9	17.5	16.0	16.6	17.3
2080s	19.7	20.5	21.4	21.9	21.5	20.1	18.9	18.9	17.0	15.8	17.0	20.0	20.1	18.8	17.4	17.9	18.5

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A58 Projections of likely changes in annual area-averaged temperatures and rainfall wrt baseline period by province

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Rainfall (%)																	
A2																	
2020s	0.8	0.3	2.7	5.0	3.4	3.5	2.8	0.8	3.9	2.4	2.9	2.5	4.0	2.4	2.5	1.7	3.5
2050s	2.1	2.0	5.5	7.0	6.5	9.4	6.9	6.7	15.2	8.4	14.6	7.6	10.1	11.6	17.0	17.5	13.1
2080s	13.9	10.9	11.9	12.1	15.2	16.2	18.5	14.2	23.7	16.1	24.2	14.3	15.7	17.1	24.2	25.2	17.6
B2																	
2020s	1.2	1.0	1.8	2.5	0.2	2.0	4.8	3.3	7.1	5.2	4.9	2.5	2.9	4.2	3.4	2.3	2.6
2050s	2.6	1.3	1.8	2.7	3.2	5.4	6.8	5.1	11.5	9.5	12.9	3.7	5.5	6.5	9.6	9.2	5.4
2080s	5.3	6.0	8.6	9.7	8.2	10.6	9.8	8.3	12.7	9.5	12.2	9.1	11.1	10.5	11.3	11.6	10.9
Maximum Temperature (°C)																	
A2																	
2020s	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.3
2050s	1.5	1.5	1.6	1.7	1.6	1.5	1.5	1.6	1.6	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.4
2080s	2.7	2.9	3.0	3.1	3.0	2.9	2.8	2.9	2.9	2.8	3.0	2.9	2.9	2.8	2.9	2.8	2.7
B2																	
2020s	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
2050s	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.3	1.2	1.2	1.2	1.2	1.2	1.2
2080s	2.0	2.0	2.1	2.2	2.2	2.1	2.0	2.1	2.2	2.1	2.3	2.1	2.1	2.1	2.2	2.1	2.0
Minimum Temperature (°C)																	
A2																	
2020s	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
2050s	1.9	1.8	1.8	1.8	1.8	1.7	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.7
2080s	3.4	3.4	3.4	3.4	3.3	3.2	3.4	3.4	3.5	3.6	3.4	3.3	3.3	3.2	3.2	3.2	3.2
B2																	
2020s	0.6	0.5	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
2050s	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.4
2080s	2.4	2.4	2.4	2.4	2.4	2.3	2.5	2.5	2.6	2.6	2.6	2.4	2.4	2.4	2.4	2.4	2.3

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A59 Projections of likely changes in area-averaged rainfall wrt baseline period in each season by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Summer																	
A2																	
2020s	-4.0	0.2	-2.2	-5.7	-14.0	-1.2	-4.1	-31.3	-17.9	2.4	-11.6	-17.5	0.0	-2.0	-0.1	-13.9	-5.9
2050s	-1.1	1.2	5.4	0.1	0.2	1.7	1.2	3.1	2.3	7.1	4.6	0.0	0.1	0.0	2.8	14.2	11.3
2080s	13.7	6.9	28.6	13.2	12.8	12.6	41.6	7.3	13.9	47.3	29.7	0.0	1.1	8.1	49.1	28.6	33.5
B2																	
2020s	-22.1	-4.5	-2.7	-7.4	-19.3	-1.2	-29.8	-46.8	-45.1	-27.7	-27.0	-47.9	-4.4	-23.8	-0.9	-15.5	-5.9
2050s	-2.7	-0.1	-2.3	-6.4	-16.4	-1.2	-5.2	-35.9	-36.6	-16.1	-10.6	-27.5	0.0	-9.7	-0.1	-12.1	-5.9
2080s	1.4	0.0	-2.0	-4.5	-15.2	-1.2	12.9	-9.2	2.8	8.3	-2.7	-9.2	0.0	-0.5	-0.1	-11.3	-5.9
Rainy																	
A2																	
2020s	6.3	6.8	11.5	6.0	9.3	9.2	8.4	4.8	7.0	4.3	4.5	6.4	5.0	5.8	7.5	6.3	10.7
2050s	4.8	1.9	7.1	6.5	6.6	14.5	11.3	10.7	22.9	10.4	17.9	13.2	14.3	21.3	23.8	23.5	21.8
2080s	-1.1	1.3	8.3	7.0	16.8	16.3	6.5	8.9	25.1	9.3	23.3	13.6	12.8	19.8	31.7	35.5	25.4
B2																	
2020s	-5.1	-1.5	1.3	0.5	-2.6	0.5	-1.8	3.7	8.0	1.1	6.0	0.6	1.8	10.7	9.1	8.2	11.9
2050s	-3.3	-1.5	-2.0	-3.3	-1.6	0.2	-1.2	1.3	12.6	8.6	11.8	-1.8	-1.8	3.7	10.9	8.2	6.3
2080s	-6.3	-4.2	3.6	2.0	8.1	11.8	0.5	6.1	12.8	8.8	11.0	2.9	6.4	12.2	16.9	20.7	19.9
Winter																	
A2																	
2020s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2050s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2080s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B2																	
2020s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2050s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2080s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A60 Projections of likely changes in area-averaged maximum temperature wrt baseline period in each season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Summer																	
A2																	
2020s	0.6	0.7	1.0	1.2	1.3	1.1	0.6	0.8	0.9	0.6	1.0	0.9	1.0	1.0	1.0	1.1	1.1
2050s	1.6	1.5	1.6	1.9	2.0	1.7	1.7	1.8	1.8	1.6	1.7	1.8	1.7	1.8	1.7	1.7	1.8
2080s	2.1	2.2	2.5	2.9	3.2	2.7	2.0	2.1	2.1	2.0	2.1	2.3	2.5	2.3	2.3	2.4	2.6
B2																	
2020s	1.4	1.5	1.8	2.0	2.0	1.9	1.3	1.6	1.6	1.3	1.8	1.7	1.8	1.8	1.8	1.9	1.9
2050s	1.4	1.5	1.7	2.0	2.2	1.9	1.5	1.7	1.8	1.6	1.8	1.7	1.8	1.9	1.9	2.0	2.1
2080s	2.3	2.4	2.7	3.0	3.2	3.0	2.3	2.6	2.6	2.3	2.7	2.7	2.8	2.8	2.8	2.9	3.0
Rainy																	
A2																	
2020s	0.6	0.6	0.6	0.6	0.5	0.6	0.7	0.8	0.7	0.8	0.6	0.7	0.7	0.6	0.6	0.5	0.5
2050s	1.6	1.5	1.7	1.8	1.7	1.8	1.6	1.7	1.6	1.6	1.4	1.8	1.8	1.7	1.6	1.5	1.6
2080s	3.5	3.7	3.9	3.9	3.5	3.7	3.6	3.9	3.6	3.5	3.3	4.0	3.9	3.6	3.5	3.2	3.4
B2																	
2020s	1.0	1.1	1.1	1.1	0.9	0.9	0.9	0.9	0.7	0.9	0.6	1.0	1.0	0.8	0.6	0.6	0.7
2050s	2.2	2.2	2.3	2.2	2.1	2.2	2.1	2.2	1.9	1.8	1.6	2.3	2.2	2.1	1.8	1.8	2.0
2080s	2.8	2.9	3.1	3.1	2.8	3.0	2.9	3.0	2.8	2.8	2.7	3.1	3.1	2.8	2.7	2.5	2.6
Winter																	
A2																	
2020s	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.3	0.3	0.2
2050s	1.1	1.2	1.3	1.4	1.5	1.2	1.2	1.2	1.4	1.2	1.7	1.2	1.2	1.2	1.4	1.4	1.3
2080s	2.5	2.6	2.7	2.8	3.0	2.7	2.8	2.8	3.2	2.9	3.5	2.7	2.7	2.7	3.0	3.0	2.8
B2																	
2020s	-0.3	-0.3	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-0.2	-0.2	0.0	-0.1	-0.1	0.0	-0.1	0.0	-0.1
2050s	0.6	0.7	0.7	0.7	0.8	0.7	0.6	0.7	0.7	0.6	1.0	0.7	0.7	0.7	0.8	0.8	0.8
2080s	1.5	1.5	1.6	1.6	1.7	1.5	1.6	1.7	1.9	1.7	2.1	1.6	1.6	1.6	1.8	1.8	1.7

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A61 Projections of likely changes in area-averaged minimum temperature wrt baseline period in each season by province (°C)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Summer																	
A2																	
2020s	0.7	0.8	0.9	0.9	1.0	0.9	0.7	0.8	0.8	0.7	0.9	0.8	0.9	0.9	0.9	0.9	0.9
2050s	2.1	2.1	2.0	2.1	2.0	2.0	2.2	2.2	2.2	2.2	2.1	2.1	2.0	2.1	2.0	2.0	2.0
2080s	3.2	3.3	3.3	3.3	3.2	3.1	3.2	3.1	3.0	3.2	2.9	3.1	3.1	3.0	2.8	2.8	2.9
B2																	
2020s	1.1	1.2	1.4	1.5	1.6	1.6	1.2	1.4	1.5	1.3	1.6	1.4	1.5	1.6	1.7	1.8	1.7
2050s	1.7	1.7	1.8	1.9	1.9	1.9	1.8	1.9	2.0	1.9	2.0	1.9	1.9	2.0	2.0	2.0	2.0
2080s	2.7	2.7	2.9	3.0	3.0	3.0	2.7	2.8	2.9	2.7	2.9	2.9	2.9	3.0	2.9	3.0	3.0
Rainy																	
A2																	
2020s	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6
2050s	1.8	1.7	1.7	1.7	1.7	1.7	1.8	1.7	1.8	1.9	1.7	1.7	1.7	1.7	1.7	1.7	1.7
2080s	3.4	3.4	3.4	3.4	3.3	3.3	3.3	3.3	3.4	3.5	3.2	3.3	3.3	3.2	3.2	3.2	3.2
B2																	
2020s	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.8	0.8
2050s	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.7
2080s	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.4	2.5	2.5	2.5	2.5	2.5	2.5
Winter																	
A2																	
2020s	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.5	0.4	0.4	0.5	0.5	0.4
2050s	2.0	2.0	2.0	2.0	2.0	1.9	1.9	2.0	2.1	1.9	2.1	2.0	1.9	1.9	2.0	2.0	1.9
2080s	3.7	3.7	3.7	3.7	3.8	3.5	3.7	3.8	3.9	3.7	3.9	3.7	3.6	3.6	3.7	3.7	3.6
B2																	
2020s	0.1	0.1	0.1	0.1	0.1	0.03	0.01	0.00	-0.03	0.01	-0.01	0.04	0.04	0.03	-0.01	0.02	0.1
2050s	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	0.9	1.1	1.1	1.1	1.0	1.0	1.1	1.1
2080s	2.3	2.3	2.3	2.3	2.4	2.2	2.3	2.3	2.4	2.2	2.4	2.3	2.3	2.3	2.4	2.4	2.3

Source Author’s calculations based upon data retrieved from the SEA START RC climate change data distribution system

Table A62 Projected population density based on medium fertility assumption by province (persons/ha)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
2020s	1.4	1.6	1.8	1.8	1.2	1.4	0.6	1.3	2.0	1.7	1.5	1.2	1.4	0.8	1.4	1.6	1.8
2050s	1.3	1.5	1.6	1.6	1.1	1.3	0.5	1.2	1.8	1.5	1.3	1.1	1.2	0.7	1.3	1.5	1.6
2080s	1.0	1.1	1.3	1.2	0.8	1.0	0.4	0.9	1.4	1.2	1.0	0.8	1.0	0.6	1.0	1.1	1.3

Source Author’s calculations based upon world population prospects: the 2012 revision from United Nations, Department of Economic and Social Affairs, Population Division (2013) and Thai demographic structure from NESDB (2011).

Table A63 Projected irrigation land based on integrated water resource management project by province (%)

	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Current	4.8	9.0	6.6	8.6	4.1	8.4	4.6	9.6	3.5	3.3	6.5	11.9	11.5	13.5	7.8	6.9	4.3
IWRM	2.3	0.5	1.5	2.4	9.4	7.8	9.1	11.0	7.5	4.3	6.4	10.9	8.0	6.1	2.2	18.2	5.2
Total	7.1	9.5	8.1	11.0	13.6	16.2	13.8	20.6	11.0	7.6	12.9	22.7	19.5	19.6	10.1	25.1	9.5

Source Author’s calculations based upon IWRM projects

Table A64 Estimated farm-level net revenue corresponding to projected climate change by province ($/ha) calculated using coefficients from climate response function – Fixed Effects Error Models in Table 6.2

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Province Fixed Effect Error Model																	
A2																	
2020s	876.6	2102.6	670.9	3169.0	2620.0	1587.9	2988.7	1489.1	2041.7	3814.9	1530.2	663.9	972.1	3159.6	3701.0	3706.2	1228.6
2050s	719.8	2032.7	87.7	2161.3	1162.4	343.4	2481.0	418.2	1058.2	2960.1	482.4	-368.7	-223.3	1581.2	2177.6	1903.5	-260.6
2080s	2113.8	3658.9	246.9	1753.8	-180.1	-535.1	3024.5	881.0	1052.3	2412.3	-638.6	191.5	-736.7	569.6	487.7	297.3	-1852.1
B2																	
2020s	760.4	1916.5	171.4	2552.0	1908.7	929.5	2786.6	1216.8	1881.8	3579.2	1419.1	491.2	454.3	2772.3	3274.1	3208.0	506.2
2050s	1235.3	2517.7	287.2	2269.9	1205.4	161.1	2727.1	928.6	1420.4	2921.1	528.1	121.2	-317.6	1603.6	2070.0	2007.2	-562.1
2080s	1334.7	2657.2	117.6	1824.0	504.0	-556.4	2586.9	414.5	775.7	2446.0	-192.2	-377.8	-1004.1	597.4	1115.0	1117.6	-1379.2
Year Fixed Effect Error Model																	
A2																	
2020s	-274.4	-56.5	-1644.9	142.0	-275.1	190.8	349.9	-62.4	-2284.5	713.7	-2175.9	-1594.2	-2062.9	-357.1	444.9	116.7	-1361.5
2050s	-1320.5	-1183.9	-2738.5	-973.2	-1309.5	-411.8	-446.0	-1340.7	-3156.9	704.6	-2717.2	-3013.1	-2553.4	-773.5	254.0	-328.3	-1801.5
2080s	-4267.3	-4976.1	-6694.8	-4512.7	-4581.7	-3078.7	-2893.0	-3777.0	-5274.5	-287.5	-5145.2	-6045.7	-4768.0	-2355.4	-1584.4	-2104.3	-4307.0
B2																	
2020s	-846.6	-797.0	-2197.6	-300.3	-699.5	-264.2	-108.0	-553.6	-2872.7	196.7	-2749.7	-1934.1	-2374.3	-628.9	-109.1	-514.2	-1971.7
2050s	-1845.4	-1922.2	-2976.1	-962.2	-1208.5	-569.8	-727.0	-1080.2	-3133.6	419.9	-3004.1	-2746.1	-2621.6	-640.5	89.7	-356.8	-2068.1
2080s	-274.4	-56.5	-1644.9	142.0	-275.1	190.8	349.9	-62.4	-2284.5	713.7	-2175.9	-1594.2	-2062.9	-357.1	444.9	116.7	-1361.5

Source Author’s calculations

Table A65 Estimated farm-level net revenue corresponding to projected climate change by province ($/ha) calculated using coefficients from climate response function – Fixed Effects Error Models with Spatial Correction in Table 6.3

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Province Fixed Effect Error Model																	
A2																	
2020s	926.3	2210.2	-52.4	2098.3	878.1	-150.3	2604.7	837.5	898.5	2203.8	331.2	-79.5	-1092.9	348.2	1127.9	1385.9	-1230.7
2050s	544.6	1804.1	-410.6	1698.1	371.2	-259.7	2318.3	150.3	406.9	2204.4	-161.3	-674.5	-1126.5	288.7	1087.7	973.8	-1283.2
2080s	-183.3	704.4	-1892.3	337.2	-1233.5	-1271.6	1662.9	-328.4	-311.4	2059.5	-1678.7	-1367.8	-1645.7	-51.0	125.0	-72.2	-2489.4
B2																	
2020s	827.0	1969.8	-317.7	1871.4	589.8	-440.7	2501.5	688.6	721.9	1956.3	140.8	-12.4	-1187.2	347.5	802.0	962.0	-1602.7
2050s	752.1	1867.1	-177.5	1990.8	692.0	-188.3	2570.8	850.9	891.0	2329.2	-41.6	-39.8	-935.7	621.7	1148.7	1241.8	-1289.2
2080s	157.3	1106.7	-1021.6	1154.9	-122.6	-910.1	1957.9	-99.5	-41.4	2180.9	-891.3	-1049.8	-1563.7	-46.0	653.8	667.0	-1959.7
Year Fixed Effect Error Model																	
A2																	
2020s	-250.9	-68.3	-1643.1	173.0	-111.9	373.2	406.5	24.1	-2168.9	983.0	-2039.4	-1553.0	-1872.1	-17.1	805.6	450.1	-1081.4
2050s	-1344.2	-1232.9	-2853.9	-1119.0	-1361.7	-458.1	-495.2	-1380.8	-3171.4	818.4	-2699.5	-3124.3	-2591.9	-705.5	363.4	-219.3	-1783.2
2080s	-4155.2	-4843.8	-6772.3	-4710.8	-4765.5	-3261.9	-2910.0	-3840.9	-5302.2	-295.1	-5155.3	-6168.0	-4955.9	-2500.3	-1662.7	-2161.3	-4472.4
B2																	
2020s	-845.3	-816.1	-2228.8	-320.7	-588.4	-134.0	-85.4	-509.4	-2789.1	444.7	-2635.1	-1956.5	-2251.7	-363.8	223.0	-203.9	-1750.4
2050s	-1831.1	-1919.1	-3079.6	-1105.3	-1268.7	-628.9	-770.8	-1148.1	-3171.4	508.6	-2996.7	-2869.5	-2679.1	-598.9	188.9	-266.9	-2075.4
2080s	-3096.6	-3530.6	-4990.1	-2988.2	-2937.1	-2268.1	-2097.8	-3032.0	-4886.4	-58.0	-4592.4	-5057.7	-4183.8	-2033.0	-955.1	-1347.3	-3534.0

Source Author's calculations

Table A66 Estimated farm-level net revenue corresponding to projected climate change and population change by province ($/ha) calculated using coefficients from climate response function – Fixed Effects Error Models in Table 6.2

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Province Fixed Effect Error Model																	
A2																	
2020s	2827.7	1297.5	3926.8	2980.1	2927.1	3414.1	2344.8	2623.2	4060.5	2170.6	1882.4	1477.4	3496.6	3988.1	4364.0	1343.6	2827.7
2050s	1780.0	-373.5	1854.7	789.2	776.1	2333.3	212.2	791.3	2852.6	310.2	-338.1	-720.3	1030.6	1730.1	1728.4	-630.1	1780.0
2080s	1137.0	-2738.6	-1023.0	-2255.1	-2206.0	1546.8	-1789.0	-1183.7	1485.1	-2696.5	-2534.4	-3559.5	-2041.1	-1664.7	-1810.8	-3345.9	1137.0
B2																	
2020s	2641.6	798.0	3309.9	2268.9	2268.7	3212.0	2072.6	2463.3	3824.8	2059.4	1709.6	959.7	3109.3	3561.2	3865.7	621.1	2641.6
2050s	2265.0	-174.0	1963.3	832.2	593.8	2579.5	722.7	1153.4	2813.6	355.9	151.8	-814.5	1053.0	1622.5	1832.0	-931.7	2265.0
2080s	135.3	-2868.0	-952.9	-1571.0	-2227.3	1109.2	-2255.5	-1460.3	1518.8	-2250.1	-3103.7	-3827.0	-2013.3	-1037.4	-990.5	-2873.1	135.3
Year Fixed Effect Error Model																	
A2																	
2020s	-58.4	-1646.5	140.0	-276.1	187.2	348.8	-64.7	-2286.1	713.1	-2177.6	-1597.5	-2064.3	-358.0	444.1	114.9	-1361.9	-58.4
2050s	-1183.3	-2737.2	-972.4	-1308.5	-413.0	-445.6	-1340.2	-3156.2	704.9	-2716.7	-3013.2	-2552.0	-772.1	255.2	-327.8	-1800.5	-1183.3
2080s	-4969.3	-6686.8	-4505.2	-4576.1	-3074.2	-2889.0	-3769.8	-5268.5	-285.0	-5139.6	-6038.4	-4760.4	-2348.4	-1578.6	-2098.7	-4303.0	-4969.3
B2																	
2020s	-798.9	-2199.3	-302.4	-700.5	-267.8	-109.2	-555.9	-2874.3	196.0	-2751.4	-1937.4	-2375.7	-629.8	-109.9	-516.0	-1972.1	-798.9
2050s	-1921.5	-2974.8	-961.3	-1207.5	-570.9	-726.6	-1079.6	-3132.9	420.2	-3003.7	-2746.2	-2620.3	-639.1	90.9	-356.3	-2067.2	-1921.5
2080s	-3557.4	-4859.3	-2781.5	-2784.0	-2106.2	-2038.2	-2926.5	-4810.0	-51.6	-4535.9	-4886.3	-4017.3	-1938.3	-909.8	-1316.4	-3408.4	-3557.4

Source Author’s calculations

Table A67 Estimated farm-level net revenue corresponding to projected climate change and population change by province ($/ha) calculated using coefficients from climate response function – Fixed Effects Error Models with Spatial Correction in Table 6.3

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Province Fixed Effect Error Model																	
A2																	
2020s	1494.3	2693.2	364.9	2603.1	1117.9	741.7	2888.0	1407.5	1285.8	2367.4	757.7	732.1	-756.3	572.7	1319.1	1823.9	-1154.1
2050s	552.5	1635.8	-717.8	1493.9	122.7	28.6	2220.0	13.1	229.0	2132.7	-276.0	-654.1	-1457.5	-78.0	789.6	857.1	-1529.3
2080s	-1474.9	-975.3	-3880.8	-1512.3	-2615.5	-2384.6	678.7	-2106.7	-1800.7	1442.0	-3049.3	-3183.4	-3525.9	-1789.8	-1308.7	-1476.3	-3484.3
B2																	
2020s	1395.0	2452.8	99.7	2376.2	829.7	451.3	2784.8	1258.6	1109.2	2119.9	567.3	799.2	-850.7	572.0	993.2	1400.1	-1526.2
2050s	760.1	1698.8	-484.7	1786.6	443.4	99.9	2472.4	713.8	713.1	2257.6	-156.3	-19.3	-1266.7	255.0	850.6	1125.2	-1535.3
2080s	-1134.3	-573.0	-3010.2	-694.6	-1504.7	-2023.0	973.7	-1877.9	-1530.7	1563.3	-2262.0	-2865.4	-3443.9	-1784.8	-779.8	-737.2	-2954.7
Year Fixed Effect Error Model																	
A2																	
2020s	-253.6	-70.6	-1645.1	170.6	-113.1	368.9	405.1	21.3	-2170.8	982.2	-2041.4	-1556.9	-1873.7	-18.2	804.6	448.0	-1081.8
2050s	-1344.2	-1232.1	-2852.4	-1118.1	-1360.5	-459.5	-494.7	-1380.1	-3170.6	818.7	-2699.0	-3124.4	-2590.3	-703.7	364.8	-218.8	-1782.0
2080s	-4149.0	-4835.7	-6762.7	-4701.9	-4758.8	-3256.6	-2905.3	-3832.4	-5295.1	-292.1	-5148.7	-6159.3	-4946.8	-2492.0	-1655.9	-2154.6	-4467.6
B2																	
2020s	-848.0	-818.4	-2230.8	-323.1	-589.5	-138.3	-86.7	-512.2	-2791.0	443.9	-2637.1	-1960.4	-2253.3	-364.9	222.1	-206.0	-1750.7
2050s	-1831.2	-1918.3	-3078.1	-1104.3	-1267.5	-630.3	-770.4	-1147.4	-3170.6	509.0	-2996.1	-2869.6	-2677.5	-597.2	190.3	-266.4	-2074.2
2080s	-3090.4	-3522.5	-4980.5	-2979.3	-2930.5	-2262.8	-2093.0	-3023.5	-4879.2	-55.0	-4585.8	-5048.9	-4174.8	-2024.7	-948.2	-1340.5	-3529.2

Source Author’s calculations

Table A68 Estimated farm-level net revenue corresponding to projected climate change, population change and irrigation land by province ($/ha) calculated using coefficients from climate response function – Fixed Effects Error Models in Table 6.2

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Province Fixed Effect Error Model																	
A2																	
2020s	2327.4	2948.8	1676.4	4544.2	5410.5	4948.7	5770.8	5190.6	4565.9	5168.9	3826.1	4685.0	3555.5	5071.6	4562.8	9059.6	2684.3
2050s	1329.8	1901.2	5.4	2472.1	3219.6	2797.8	4690.0	3058.0	2734.0	3961.1	1965.7	2464.6	1357.9	2605.6	2304.7	6424.0	710.6
2080s	772.6	1258.1	-2359.7	-405.6	175.3	-184.4	3903.5	1056.8	759.0	2593.6	-1041.0	268.3	-1481.4	-466.0	-1090.0	2884.8	-2005.2
B2																	
2020s	2211.2	2762.7	1176.9	3927.2	4699.3	4290.4	5568.7	4918.3	4406.0	4933.3	3714.9	4512.3	3037.8	4684.4	4135.8	8561.3	1961.9
2050s	1845.3	2386.1	205.0	2580.7	3262.6	2615.5	4936.1	3568.5	3096.1	3922.1	2011.4	2954.5	1263.7	2628.0	2197.2	6527.6	409.1
2080s	-6.5	256.5	-2489.0	-335.5	859.4	-205.6	3465.9	590.3	482.4	2627.3	-594.6	-301.1	-1748.8	-438.2	-462.7	3705.1	-1532.3
Year Fixed Effect Error Model																	
A2																	
2020s	78.6	13.6	-1421.4	506.8	1167.9	1388.4	1749.0	1626.0	-1131.8	1371.7	-1194.0	67.7	-829.6	577.7	785.6	2904.8	-565.3
2050s	-965.3	-1111.3	-2512.1	-605.6	135.5	788.2	954.6	350.6	-2002.0	1363.5	-1733.1	-1348.0	-1317.3	163.7	596.6	2462.0	-1003.9
2080s	-3906.8	-4897.3	-6461.7	-4138.4	-3132.1	-1873.0	-1488.8	-2079.1	-4114.2	373.6	-4156.0	-4373.2	-3525.7	-1412.6	-1237.2	691.2	-3506.4
B2																	
2020s	-493.6	-726.9	-1974.1	64.4	743.5	933.4	1291.0	1134.9	-1720.0	854.6	-1767.8	-272.2	-1141.0	305.9	231.6	2273.8	-1175.5
2050s	-1490.2	-1849.5	-2749.7	-594.5	236.5	630.2	673.6	611.1	-1978.7	1078.8	-2020.1	-1081.0	-1385.6	296.7	432.4	2433.5	-1270.6
2080s	-2766.6	-3485.4	-4634.2	-2414.7	-1340.0	-905.0	-638.1	-1235.7	-3655.7	607.0	-3552.3	-3221.1	-2782.6	-1002.5	-568.4	1473.4	-2611.8

Source Author's calculations

Table A69 Estimated farm-level net revenue corresponding to projected climate change, population change and irrigation land by province ($/ha) calculated using coefficients from climate response function – Fixed Effects Error Models with Spatial Correction in Table 6.3

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
Province Fixed Effect Error Model																	
A2																	
2020s	2306.4	2857.7	879.5	3441.5	4418.4	3487.1	6088.4	5272.1	3924.1	3872.7	3005.9	4538.1	2065.8	2711.6	2099.5	8200.6	666.6
2050s	1364.6	1800.3	-203.2	2332.3	3423.2	2774.0	5420.4	3877.7	2867.3	3638.0	1972.1	3151.9	1364.7	2060.9	1570.0	7233.8	291.4
2080s	-662.8	-810.8	-3366.2	-673.9	685.0	360.9	3879.1	1757.8	837.5	2947.3	-801.2	622.6	-703.8	349.1	-528.2	4900.3	-1663.6
B2																	
2020s	2207.1	2617.3	614.3	3214.6	4130.2	3196.7	5985.2	5123.1	3747.5	3625.2	2815.4	4605.1	1971.5	2710.9	1773.6	7776.7	294.5
2050s	1572.2	1863.3	29.9	2625.0	3743.9	2845.4	5672.8	4578.3	3351.4	3762.9	2091.9	3786.7	1555.5	2393.9	1631.1	7501.8	285.4
2080s	-322.2	-408.5	-2495.6	143.8	1795.8	722.4	4174.1	1986.7	1107.5	3068.7	-13.8	940.6	-621.8	354.1	0.6	5639.5	-1133.9
Year Fixed Effect Error Model																	
A2																	
2020s	99.7	1.0	-1421.2	535.3	1322.9	1563.4	1797.6	1702.8	-1022.9	1637.1	-1063.3	99.0	-645.8	912.4	1144.2	3222.3	-289.6
2050s	-990.9	-1160.5	-2628.5	-753.3	75.5	735.0	897.7	301.3	-2022.7	1473.7	-1720.9	-1468.5	-1362.4	226.9	704.3	2555.6	-989.8
2080s	-3795.6	-4764.1	-6538.8	-4337.1	-3322.8	-2062.1	-1512.8	-2151.0	-4147.2	362.8	-4170.5	-4503.4	-3719.0	-1561.4	-1316.3	619.8	-3675.4
B2																	
2020s	-494.7	-746.8	-2007.0	41.7	846.5	1056.2	1305.7	1169.2	-1643.1	1098.9	-1659.0	-304.5	-1025.5	565.7	561.6	2568.4	-958.6
2050s	-1477.9	-1846.7	-2854.2	-739.6	168.4	564.2	622.1	534.0	-2022.7	1163.9	-2018.0	-1213.7	-1449.7	333.4	529.9	2508.0	-1282.0
2080s	-2737.1	-3450.9	-4756.6	-2614.5	-1494.5	-1068.3	-700.6	-1342.1	-3731.3	599.9	-3607.7	-3393.0	-2946.9	-1094.1	-608.6	1433.9	-2737.1

Source Author’s calculations

Table A70 Estimated farm-level net revenue using coefficients from the province spatial fixed effects error model in Table 6.3 ($/ha)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	-225	-103	-626	882	-610	1001	617	-2297	-800	305	-1209	-1559	-679	-2412	92	676	-45
1985	769	610	-100	1811	200	1255	1194	135	-304	1066	-458	-943	-426	-745	1067	1268	171
1986	463	88	97	1668	-125	1229	851	439	-89	1095	-597	-1147	-282	-609	1038	1384	649
1987	177	434	240	1688	-398	1042	970	301	-219	706	369	-1219	-284	-609	813	1099	-149
1988	1233	1235	995	2290	549	942	1308	1085	218	1022	930	-180	266	2	1286	1438	711
1989	392	475	319	1888	309	900	807	616	-233	760	779	-475	-432	-13	1032	1650	398
1990	467	1005	592	1914	99	570	1321	856	0	815	630	-43	-50	141	991	1642	371
1991	606	953	424	1665	164	624	1393	1022	422	640	1118	164	-133	179	1269	1342	247
1992	643	845	662	1839	-11	803	1020	677	286	674	516	120	62	511	1154	1679	636
1993	1489	2018	1733	2900	1111	2096	2332	1203	891	1874	977	904	916	1103	1714	2328	1193
1994	811	1443	1066	2636	1096	1475	1210	1153	948	1445	1113	742	619	591	1758	2132	682
1995	791	1793	1431	3229	1638	2023	1280	708	650	1092	892	973	856	836	1265	1756	579
1996	1876	2859	2623	4532	2889	3980	3219	2539	2648	4233	3852	2604	2715	2554	3398	3837	2789
1997	1824	2240	1869	3917	1996	2031	3334	2183	2077	3647	2774	1814	1040	1619	3056	3219	1046
1998	885	1598	1269	2655	1077	1510	2446	941	1618	2319	1657	616	815	1092	1535	1695	464
1999	1952	3378	2767	4555	2525	1998	3829	2711	2626	3475	2622	2224	1986	2217	2430	1745	816
2000	2087	2644	1887	4077	2350	2428	3736	2279	2203	4044	2920	870	1546	2608	3565	2899	1337
2001	956	1958	1741	3227	1219	855	2378	907	736	1954	1523	477	77	629	1401	1412	-180
2002	1445	2070	1184	2382	1326	1447	3024	1659	1446	2243	1518	930	357	1160	2202	1770	-1330
2003	1534	2951	1605	3479	1836	1344	3074	1604	2128	2608	1831	1015	258	1428	2065	1951	452
2004	1255	2439	679	2596	1338	1664	3067	1562	2793	3333	2673	1211	311	1833	3432	2764	1093
2005	1635	3027	1161	3075	1675	1539	3560	1826	2082	2853	1754	1252	657	1736	2101	2643	614
2006	1768	3030	1460	3131	2072	1755	3760	2030	2616	4183	2442	1576	781	2212	2755	2609	856
2007	1398	2336	693	2218	1541	962	3396	1623	1754	2847	1648	815	-87	1612	2076	1780	146
2008	1883	2895	1391	3326	2240	1980	4783	2549	3018	4715	2491	1565	980	2743	3371	2896	1481
2009	2060	2913	1498	3708	2589	920	4247	1805	3038	5024	1731	871	81	1929	3408	2981	981
2010	837	2166	361	2765	1585	804	2889	1161	1210	2696	1400	223	-288	1466	2448	2569	-66

Source Author’s calculations

Table A71 Estimated farm-level net revenue using coefficients from the year spatial fixed effects error model in Table 6.3($/ha)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	306	961	-55	1136	218	1803	467	-946	-231	-92	-938	-792	-329	-199	399	1104	-131
1985	403	1358	184	1113	-58	1508	271	-117	-414	219	-929	-759	-908	-1001	-59	-256	-886
1986	-335	625	-81	1227	-33	1291	-217	6	-460	-163	-1332	-684	-348	-201	13	451	-135
1987	-305	695	-62	1038	-120	1723	258	245	421	444	155	-789	-414	-365	330	527	-655
1988	691	1384	762	995	-49	793	584	508	365	194	-140	-229	-243	-254	107	575	-546
1989	-223	411	153	1169	416	2023	0	428	186	419	-74	-270	-332	190	607	1141	495
1990	-997	1682	703	1593	406	1628	-510	210	323	230	-274	-243	-31	385	1201	1389	434
1991	911	1570	709	1468	516	1885	1637	670	596	1024	-63	-194	-157	61	616	793	128
1992	868	1126	381	1154	194	1724	672	435	-213	103	-749	369	130	529	152	717	346
1993	901	1875	1284	1630	638	2756	1100	210	412	649	-122	305	525	424	532	1183	574
1994	588	1082	900	1563	845	2453	1144	730	1129	1222	394	-153	143	-97	1278	1729	584
1995	1685	2505	1891	2552	1783	3174	1792	1166	1676	2478	1385	983	1227	1323	1793	2090	1024
1996	4135	5045	4078	5337	4377	5798	4679	3947	3144	4997	3642	4247	3674	3518	3624	3966	3680
1997	2248	2780	2912	3759	2576	3728	3110	2065	2336	3580	2794	1794	1662	1953	3019	3928	2351
1998	2363	2818	2512	2809	2291	3030	3042	1757	2935	3689	2893	1529	2172	2333	2496	3178	1676
1999	781	3242	3098	3241	2921	2569	3154	3174	2722	3381	2574	2670	2344	2277	1762	1455	1102
2000	1352	1715	1331	1724	891	1262	2057	1172	1290	3173	1586	-330	713	1193	1950	1772	738
2001	1450	2033	1976	2019	801	2269	2557	1114	618	2257	1616	386	714	527	1719	1962	590
2002	2184	2537	2583	1991	900	2049	2961	1183	1428	2446	2145	752	1096	491	2152	1753	393
2003	1514	2013	604	1742	1219	1834	1720	137	976	2034	1284	-136	-16	-1203	1272	1424	440
2004	1288	1982	709	819	148	759	1956	363	1687	2639	1411	117	280	140	2325	1536	427
2005	603	1905	710	1023	1097	657	1675	880	1539	2222	2089	589	491	-253	2057	2358	-912
2006	1213	2044	710	1410	1322	1106	2688	1117	1859	3888	1653	598	486	345	2050	1801	236
2007	2279	2906	805	1512	1561	2135	3339	1837	2063	5367	1842	931	950	1146	2327	2912	810
2008	3978	4208	2544	3433	3242	3734	5644	3905	3878	7269	3429	2585	2070	3545	5017	4137	2623
2009	3781	3997	3187	4756	4341	4024	5465	4281	3715	7038	2824	1391	1353	4235	5799	4675	3670
2010	1777	1791	235	1867	1440	2231	3001	1872	814	3613	1421	-254	-404	1599	3501	2977	1144

Source Author’s calculations

Table A72 Percentage difference between observed and estimated farm-level net revenue using coefficients from the province spatial fixed effects error model in Table 6.3 by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	-23.6	-99.2	-559.0	421.1	-317.3	458.5	255.7	-1960.8	-727.6	-13.9	-439.7	-733.6	-782.2	-1822.9	-13.8	587.1	-989.6
1985	36.0	1094.5	-613.4	7085.3	-104.1	-1998.2	8371.6	301.7	-394.3	-1058.5	-894.3	-1706.5	-3737.9	-2179.4	-6919.6	-852.4	1152.4
1986	17.6	979.2	-5.3	3661.3	-81.1	-4041.3	450.7	-50.0	-159.7	1186.5	-369.3	-643.2	-1123.3	-1177.1	1871.3	1268.8	1244.5
1987	-7.3	79.3	78.0	1448.6	-328.5	296.8	589.9	32.5	-229.0	176.6	33.4	-469.9	-604.1	-769.3	785.6	702.9	-205.6
1988	31.3	158.0	306.5	1060.9	19.7	171.4	491.0	203.9	-64.8	125.6	131.7	-135.9	46.3	-236.5	309.1	554.5	324.7
1989	-26.0	21.5	56.7	990.7	-101.5	104.0	98.4	23.0	-159.1	25.8	73.4	-259.5	-163.4	-265.5	183.2	541.2	58.6
1990	-18.9	81.2	133.8	453.0	-29.5	52.4	191.6	68.8	-159.6	33.8	56.9	-151.7	-87.0	-88.4	142.3	316.3	-44.8
1991	-13.4	50.1	29.9	-921.7	-5.7	57.3	146.3	53.2	-33.5	3.8	111.0	-75.2	-107.8	-84.5	175.6	254.9	-33.1
1992	104.9	-32.2	114.4	-1155.2	-13.3	75.1	82.7	16.1	-49.4	137.6	-1072.5	47.8	-101.8	10.4	182.9	432.0	103.5
1993	122.4	109.7	6.4	-182.4	12.2	469.9	275.0	39.6	68.1	327.7	-4969.0	-69.9	367.6	499.8	480.7	149.7	49.8
1994	36.8	1192.7	168.4	-723.3	5.0	42.3	51.8	106.8	-244.3	47.6	283.1	-194.3	84.9	73.3	92.7	3.6	2.1
1995	-64.0	-31.7	34.9	-535.7	-12.0	61.8	-374.3	-6.3	-304.3	24.1	268.8	141.7	12.5	3.1	55.5	-298.6	-5.9
1996	-76.9	-75.6	-70.3	-78.4	-19.9	-32.3	-45.3	-7.4	-76.3	56.7	94.9	-2.4	-6.0	-6.6	39.0	-171.0	26.1
1997	-28.4	-11.3	-29.6	-23.6	-20.7	-31.6	6.8	-14.3	-77.8	60.0	25.0	-21.9	-44.0	-40.6	-12.1	-34.0	12.0
1998	-43.8	-69.9	-48.9	-6.5	-54.2	-38.1	-26.3	-47.5	-93.8	-14.1	-47.7	-57.9	-47.9	-62.1	-64.9	-49.6	7.1
1999	25.3	4.4	-44.1	-28.4	-5.8	-23.7	67.1	9.2	28.7	86.8	43.7	3.1	8.5	3.1	29.4	-2.7	-88.3
2000	51.0	154.4	97.8	134.3	48.9	194.8	294.1	8.2	49.2	242.6	197.4	-178.7	14.1	74.7	124.5	132.6	-78.4
2001	-75.0	6.8	47.9	249.9	71.1	-36.4	-246.7	-21.0	58.3	-78.8	53.0	-157.2	-68.4	-57.8	-22.4	26.8	-195.1
2002	-57.8	-23.2	-10.4	2.5	10.7	-54.4	-78.2	-1.3	91.1	-994.8	-12.6	-26.7	-38.9	25.4	25.8	22.1	-208.8
2003	24.4	44.5	16.0	225.2	195.0	72.9	57.2	0.9	259.0	-90.5	12.4	-2.2	-9.2	258.5	39.8	64.3	-47.3
2004	43.6	224.8	32.3	2083.6	-191.0	-392.8	5467.0	-19.6	166.5	721.4	-27.4	15.2	92.9	-671.3	-496.2	28.7	34.4
2005	70.0	884.8	118.0	-96852	-250.2	-1968.7	229.6	103.0	171.4	-138.6	-44.5	34.8	-6489.1	-168.8	-197.9	3.3	8.2
2006	61.2	258.2	4.4	47.9	11.4	-120.2	11.7	56.5	2682.1	43.3	-32.5	57.6	-226.4	-308.9	114.4	45.5	82.5
2007	-75.4	-1.5	-23.8	-34.3	-13.5	-50.7	-51.1	1.0	-9.6	-175.5	-35.5	45.3	-31.1	-287.4	16.1	-20.4	-13.2
2008	-46.2	-101.6	-3.9	-67.9	-33.9	-83.1	-52.8	-4.5	-53.7	-99.7	-11.2	75.6	-106.1	499.1	-55.5	-47.2	12.1
2009	8.2	-159.6	-17.7	-25.0	-24.5	-143.6	-30.7	-7.2	-96.5	-108.8	-7.0	28.8	-155.7	-500.2	-106.4	-22.8	-8.9
2010	-76.8	10.2	119.7	114.4	51.8	-214.3	132.6	-6.0	61.4	-975.9	-1.5	100.0	-98.2	-10.3	-223.0	-79.3	11.3

Source Author's calculations

Table A73 Percentage difference between observed and estimated farm-level net revenue using coefficients from the year spatial fixed effects error model in Table 6.3 by province (%)

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
1984	25.7	592.4	-136.3	358.1	23.5	835.3	276.8	-820.7	-248.9	-128.2	-513.8	-855.7	-334.3	-231.4	253.2	8347.4	-255.2
1985	647.7	6364.6	532.5	-543.2	-5.9	10715.9	898.1	-322.4	334.3	281.9	-1759.4	-6277.6	-2821.3	5612.3	-59.6	-1182.4	770.2
1986	-394.5	-161.0	-293.6	866.7	47.9	281.9	-67.8	-94.3	-716.8	-177.3	-828.1	-2370.6	-721.8	-503.5	-87.5	639.3	21.6
1987	-194.3	290.4	-161.4	379.1	-138.3	1448.2	-17.8	23.3	78.0	54.0	-43.2	-1372.1	-558.5	-525.5	138.2	322.6	-707.9
1988	13.3	409.5	370.6	74.0	-111.2	309.4	63.3	42.4	-18.9	-57.6	-142.7	-186.1	-269.7	-174.5	-53.6	266.0	-372.1
1989	-124.5	46.6	-3.8	281.3	-33.0	693.4	-100.0	-12.3	-65.8	-32.4	-122.8	-174.0	-301.9	-55.3	138.6	319.8	107.6
1990	-218.3	423.5	332.9	35.2	-9.0	385.1	-175.2	-46.3	-48.0	-61.9	-195.7	-162.1	-110.5	-3.0	182.6	366.2	-13.9
1991	4.3	204.5	163.4	-64.6	29.4	376.1	101.3	13.6	-3.7	66.2	-114.5	-139.5	-139.8	-88.2	67.1	97.3	-66.4
1992	-160.0	196.8	67.2	-74.2	-66.7	372.9	-6.4	-22.5	-137.8	-202.5	32.4	-5.3	-71.7	14.2	-50.3	101.6	29.2
1993	-194.8	-38.8	-16.5	-71.4	54.6	1648.3	-42.0	-53.4	-29.4	-1730.5	-87.8	48.8	224.4	43.8	78.3	-37.2	124.0
1994	653.3	111.2	343.8	-61.9	-5.3	123.3	78.6	55.5	-46.1	172.5	-351.8	-135.0	-42.1	-123.7	-7.3	-17.0	-8.6
1995	-18.5	2.3	228.3	-59.6	-25.6	484.6	-45.9	27.1	-51.3	842.3	647.7	38.4	60.0	62.9	120.2	-50.1	24.2
1996	21.2	-7.3	-36.7	-44.3	-8.8	4.9	-18.3	33.1	-36.0	244.5	47.1	59.4	27.8	28.2	55.8	-49.3	390.1
1997	-6.0	10.7	11.4	-17.1	-12.3	26.0	-0.8	-21.5	-43.4	205.3	12.6	-23.9	-20.1	-20.7	-10.0	-9.9	350.9
1998	34.2	-0.4	-5.3	-0.7	-12.2	21.0	-2.0	-27.3	-24.4	28.6	-4.4	-35.4	11.5	1.4	-17.6	-0.6	604.7
1999	-46.0	-2.2	-26.7	-43.7	2.2	-3.9	55.0	25.7	43.2	85.3	41.1	23.2	30.2	5.4	-1.8	-18.8	-54.0
2000	26.7	72.2	45.9	-39.5	-6.9	123.6	-0.9	-44.4	10.5	161.4	202.3	-118.2	-44.8	-27.4	28.3	100.2	-63.7
2001	-40.9	13.5	123.8	98.0	62.1	119.3	-48.1	-42.6	-256.0	37.5	147.4	-74.4	-35.4	-58.5	2.1	104.5	-65.1
2002	-16.1	-5.1	76.8	-15.1	-16.3	0.9	-35.8	-31.1	-1315.2	127.7	29.7	-45.1	23.2	-47.5	9.7	31.1	-73.1
2003	44.9	-19.0	-50.0	129.1	245.5	68.7	-29.9	-91.3	-149.5	146.1	-25.7	-112.9	-104.4	-336.4	-31.7	89.0	-45.6
2004	238.3	25.2	320.4	-189.3	-135.7	2037.5	73.6	-79.6	-1060.8	-42.6	-64.1	-80.9	-208.3	47.2	-40.4	-6.4	-19.1
2005	161.7	93.0	-18403.5	-250.5	-4422.1	-36.8	42.7	42.6	50.2	-48.0	-42.8	-3105.6	-179.9	-136.3	-40.9	-6.8	-324.5
2006	124.2	25.2	-48.8	-42.8	-26.2	-71.7	-18.5	571.7	-200.7	-21.9	-59.3	-178.3	-151.2	-148.0	-42.7	83.6	410.0
2007	-21.7	22.2	-36.1	-43.0	-17.8	11.0	-23.7	16.3	8.2	-13.3	-52.1	-200.2	-352.9	115.3	16.9	33.1	86.3
2008	41.5	-26.9	57.5	-22.4	-13.3	-26.6	-24.4	35.3	-15.1	-21.6	-2.9	-333.5	-1163.7	-4.5	-7.6	-24.2	219.4
2009	99.5	-32.7	25.1	9.5	18.8	-34.8	-11.0	90.6	-28.7	-34.2	13.8	786.0	315.8	19.0	-19.4	1.1	163.9
2010	-25.4	-6.9	-112.1	-62.6	-244.2	-267.0	-35.6	29.9	149.6	-38.5	-4.6	-80.0	-73.6	22.2	-34.8	-56.4	-236.3

Source Author’s calculations

Table A74 Percentage difference between observed and estimated farm-level net revenue for using coefficients from the spatial fixed effects error model in Table 6.3 for the Northeast region calculated with the averaged values at the regional level.

Year	Observed NR ($/ha)	Estimated NR using Province sfem ($/ha)	Difference (%)	Estimated NR using Year sfem ($/ha)	Difference (%)
1984	160	-335	-588.0	158	-1.5
1985	-17	387	-396.8	-19	12.9
1986	-20	362	-344.9	-22	11.2
1987	186	292	98.2	184	-1.2
1988	325	902	287.1	323	-0.6
1989	399	540	59.0	397	-0.6
1990	481	666	36.7	478	-0.5
1991	719	712	-1.8	716	-0.4
1992	470	713	90.6	467	-0.7
1993	877	1575	272.5	875	-0.3
1994	916	1231	49.2	914	-0.3
1995	1799	1282	-62.7	1796	-0.2
1996	4230	3126	-147.0	4229	0.0
1997	2743	2335	-78.2	2741	-0.1
1998	2563	1423	-479.3	2560	-0.1
1999	2500	2580	3.3	2498	-0.1
2000	1389	2558	57.6	1388	-0.1
2001	1451	1251	-11.8	1448	-0.2
2002	1711	1461	-17.1	1708	-0.1
2003	994	1833	103.8	992	-0.2
2004	1096	2003	171.9	1093	-0.2
2005	1104	1952	208.9	1102	-0.2
2006	1445	2296	1838.5	1443	-0.1
2007	2045	1574	-108.3	2043	-0.1
2008	3840	2606	-150.2	3838	-0.1
2009	4033	2340	-121.7	4031	0.0
2010	1687	1425	31.2	1684	-0.2

Source Author’s calculations

Table A75 Projected farm-level net revenue corresponding to projected climate change by province ($/ha) calculated using coefficients from the year spatial fixed effects error model in Table 6.3

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
A2																	
2020s	-250.9	-68.3	-1643.1	173.0	-111.9	373.2	406.5	24.1	-2168.9	983.0	-2039.4	-1553.0	-1872.1	-17.1	805.6	450.1	-1081.4
2050s	-1344.2	-1232.9	-2853.9	-1119.0	-1361.7	-458.1	-495.2	-1380.8	-3171.4	818.4	-2699.5	-3124.3	-2591.9	-705.5	363.4	-219.3	-1783.2
2080s	-4155.2	-4843.8	-6772.3	-4710.8	-4765.5	-3261.9	-2910.0	-3840.9	-5302.2	-295.1	-5155.3	-6168.0	-4955.9	-2500.3	-1662.7	-2161.3	-4472.4
B2																	
2020s	-845.3	-816.1	-2228.8	-320.7	-588.4	-134.0	-85.4	-509.4	-2789.1	444.7	-2635.1	-1956.5	-2251.7	-363.8	223.0	-203.9	-1750.4
2050s	-1831.1	-1919.1	-3079.6	-1105.3	-1268.7	-628.9	-770.8	-1148.1	-3171.4	508.6	-2996.7	-2869.5	-2679.1	-598.9	188.9	-266.9	-2075.4
2080s	-3096.6	-3530.6	-4990.1	-2988.2	-2937.1	-2268.1	-2097.8	-3032.0	-4886.4	-58.0	-4592.4	-5057.7	-4183.8	-2033.0	-955.1	-1347.3	-3534.0

Source Author’s calculation s

Table A76 Projected farm-level net revenue corresponding to projected climate change and population density change by province ($/ha) calculated using coefficients from the year spatial fixed effects error model in Table 6.3

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
A2																	
2020s	-253.6	-70.6	-1645.1	170.6	-113.1	368.9	405.1	21.3	-2170.8	982.2	-2041.4	-1556.9	-1873.7	-18.2	804.6	448.0	-1081.8
2050s	-1344.2	-1232.1	-2852.4	-1118.1	-1360.5	-459.5	-494.7	-1380.1	-3170.6	818.7	-2699.0	-3124.4	-2590.3	-703.7	364.8	-218.8	-1782.0
2080s	-4149.0	-4835.7	-6762.7	-4701.9	-4758.8	-3256.6	-2905.3	-3832.4	-5295.1	-292.1	-5148.7	-6159.3	-4946.8	-2492.0	-1655.9	-2154.6	-4467.6
B2																	
2020s	-848.0	-818.4	-2230.8	-323.1	-589.5	-138.3	-86.7	-512.2	-2791.0	443.9	-2637.1	-1960.4	-2253.3	-364.9	222.1	-206.0	-1750.7
2050s	-1831.2	-1918.3	-3078.1	-1104.3	-1267.5	-630.3	-770.4	-1147.4	-3170.6	509.0	-2996.1	-2869.6	-2677.5	-597.2	190.3	-266.4	-2074.2
2080s	-3090.4	-3522.5	-4980.5	-2979.3	-2930.5	-2262.8	-2093.0	-3023.5	-4879.2	-55.0	-4585.8	-5048.9	-4174.8	-2024.7	-948.2	-1340.5	-3529.2

Source Author’s calculations

Table A77 Projected farm-level net revenue corresponding to projected climate change, population change and irrigation land by province ($/ha) calculated using coefficients from the year spatial fixed effects error model in Table 6.3

Year	nm	br	sr	ss	ub	ys	cp	kk	ud	lo	nk	mk	re	ks	sk	np	mh
A2																	
2020s	99.7	1.0	-1421.2	535.3	1322.9	1563.4	1797.6	1702.8	-1022.9	1637.1	-1063.3	99.0	-645.8	912.4	1144.2	3222.3	-289.6
2050s	-990.9	-1160.5	-2628.5	-753.3	75.5	735.0	897.7	301.3	-2022.7	1473.7	-1720.9	-1468.5	-1362.4	226.9	704.3	2555.6	-989.8
2080s	-3795.6	-4764.1	-6538.8	-4337.1	-3322.8	-2062.1	-1512.8	-2151.0	-4147.2	362.8	-4170.5	-4503.4	-3719.0	-1561.4	-1316.3	619.8	-3675.4
B2																	
2020s	-494.7	-746.8	-2007.0	41.7	846.5	1056.2	1305.7	1169.2	-1643.1	1098.9	-1659.0	-304.5	-1025.5	565.7	561.6	2568.4	-958.6
2050s	-1477.9	-1846.7	-2854.2	-739.6	168.4	564.2	622.1	534.0	-2022.7	1163.9	-2018.0	-1213.7	-1449.7	333.4	529.9	2508.0	-1282.0
2080s	-2737.1	-3450.9	-4756.6	-2614.5	-1494.5	-1068.3	-700.6	-1342.1	-3731.3	599.9	-3607.7	-3393.0	-2946.9	-1094.1	-608.6	1433.9	-2737.1

Source Author's calculations

Abbreviations

Provinces in Northeast Thailand

nm	Nakhon Ratchasima
br	Buri Ram
sr	Surin
ss	Si Sa Ket
ub	Ubon Ratchathani
ys	Yasothon
cp	Chaiyaphum
kk	Khon Kaen
ud	Udon Thani
lo	Loei
nk	Nong Khai
mk	Maha Sarakham
re	Roi Et
ks	Kalasin
sk	Sakon Nakhon
np	Nakhon Phanom
mh	Mukdahan
nb	Nong Bua Lam Phu
an	Am Nat Chareon

Economy Crops

PD	Paddy 1st and 2nd crops
CV	Cassava
SC	Sugarcane
MZ	Maize
MB	Mungbeans
GN	Groundnuts
SB	Soybeans
KN	Kenaf
CT	Cotton
GL	Garlic
PT	Potato
SL	Shallot
PR	Para rubber
DR	Durians
LG	Longans
OR	Oranges
PA	Pineapples

Table A78 Climate Response Function – Panel Data Models

Variable	Fixed Effects Model		Lagged	Random Effects
	Province	Year	Model	Model
R_summer	207.0(1.66).	240.3(2.17)*	-3434.4(-0.38)	304.0(2.41)*
R_rainy	-0.9(-0.02)	21.3(0.45)	789.8(0.35)	6.1(0.11)
R_winter	-366.6(-1.22)	-284.3(-0.95)	582.0(0.06)	-242.3(-0.78)
R_summer sq.	-0.1(-2.22)*	-0.1(-1.96)	1.2(0.28)	-0.1(-2.81)**
R_rainy sq.	0.006(1.16)	0.006(1.18)	-0.02(-0.11)	0.004(0.71)
R_winter sq.	-0.5(-0.68)	0.2(0.28)	-4.6(-0.16)	-0.5(-0.64)
Tx_summer	807.9(0.19)	8648.7(2.07)*	-88545.0(-0.38)	1399.8(0.33)
Tx_rainy	-13456.0(-1.18)	11346.0(0.99)	234390.0(0.51)	-13835.0(-1.18)
Tx_winter	319.8(0.19)	3898.9(1.69).	6032.7(0.33)	-472.5(-0.28)
Tx_summer sq.	-10.8(-0.20)	-114.8(-2.06)*	1127.5(0.38)	-16.3(-0.29)
Tx_rainy sq.	213.1(1.23)	-185.2(-1.07)	-3524.6(-0.50)	220.0(1.24)
Tx_winter sq.	-5.1(-0.18)	-61.6(-1.62)	-99.3(-0.32)	8.8(0.31)
TxR_summer	-5.1(-1.57)	-6.1(-2.07)*	89.7(0.39)	-7.7(-2.33)*
TxR_rainy	-0.1(-0.08)	-0.8(-0.59)	-24.5(-0.35)	-0.3(-0.18)
TxR_winter	13.7(1.38)	9.7(0.97)	-11.7(-0.04)	9.6(0.94)
Pop density	6724.8(3.18)**	-18.1(-0.04)	18342.0(1.39)	600.0(0.99)
Irrigated land	258.2(2.44)*	153.4(3.96)***	699.4(0.74)	101.9(1.88).
Literacy	1149.1(2.68)**	136.9(0.33)	2055.2(0.25)	933.8(2.16)*
Bullocks	67.4(6.40)***	54.1(6.94)***	67.4(0.98)	68.7(7.02)***
Tractors	106.6(4.45)***	72.9(3.33)***	47.1(0.28)	161.2(7.85)***
Cultivators	129.4(0.57)	-1713.7(-6.43)***	-540.9(-0.50)	-160.2(-0.73)
Alfisols		11.9(0.44)		66.4(1.56)

Variable	Fixed Effects Model		Lagged	Random Effects
	Province	Year	Model	Model
Inceptisols		17.2(0.72)		50.9(1.33)
Oxisols		463.0(8.75)***		321.3(4.82)***
Ultisols		42.7(1.57)		91.8(2.23)*
Vertisols		609.2(8.41)***		401.4(4.07)***
Intercept				86459.0
Observations	459	459	442	459
Adjusted R^2	0.3450	0.2870	0.0155	0.3372
F stat. (p-value)	12.09(0)***	7.50(0)***	-12.30(1)	9.27(0)***
d stat. (p-value)	0.97(0)***	1.99(0.5015)	0.98(0)***	0.90(0.7610)

Source Author’s calculation